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PSYCHOPHYSIOLOGICAL ASSESSMENT OF PILOT WORKLOAD IN AN APPLIED SETTING

BY

JOHN STEVEN BELL

B.S., Arizona State University, 1981

THESIS

Submitted in partial fulfillment of the requirements
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PSYCHOPHYSIOLOGICAL ASSESSMENT OF PILOT WORKLOD IN AN APPLIED SETTING

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Abstract

The use of a single measure of workload is not sufficient to adequately assess the multidimensional nature of workload in an applied setting. This study was designed to determine how varying degrees of communication load effect a pilots' workload and his resulting performance in a new-concept high-fidelity helicopter cockpit simulator. The study also examined the relations among performance-based, subjective, and cardiovascular measures of operator workload. Six male volunteers, former or current military helicopter pilots, participated in the study. The pilots each flew two missions in a fixed-base, high-fidelity simulator equipped with a new-concept cockpit. The flights varied only in the difficulty of the communication requirements. Performance and cardiovascular measures were recorded throughout each mission. Subjective ratings, using the NASA-TLX scales, were recorded after each mission. All three measures failed to discriminate workload levels between the two missions but were sensitive to within-mission differences. Unexpectedly, T-wave amplitude, power in the .06-.14 Hz band, and in the .1 Hz spectral component increased during periods of high communication. In sum, the measures provided evidence that mission workload and performance were within acceptable limits and within-mission differences could be discriminated.

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INTRODUCTION

General Overview

One of the greatest problems facing researchers, design teams, and practitioners of engineering psychology is to determine that the product of their labors, whether a new type of computer interface or a new concept cockpit in a next generation aircraft, places demands upon the operator that are consistent with the known limits of human performance capacities. It is one thing to have a machine that performs a task with great efficiency. It is quite another to place a human operator at the controls of this machine and obtain ideal performance efficiency levels. Engineers are most concerned that the machine they have constructed is functionally capable of performing the operations it was designed for and sustaining its function within some specified lifetime. The machine's functional parameters are easily tested and relatively well understood.

The engineering psychologist faces the same problem but is primarily concerned with the human side of the system. Unfortunately, human performance is not nearly as easy to predict. In the operational environment, one way to look at human performance is to examine workload. In the past, the tasks operators were required to perform entailed high levels of physical workload which was relatively easy to measure and quantify. As task automation has increased, the nature of the work has become increasingly cognitive. As a result, a variety of techniques have

been applied to operational situations to identify cognitive or "mental" workload. The present study attempts to provide a comprehensive evaluation of the workload demands imposed on a pilot in a new concept helicopter cockpit. A number of different workload metrics were employed in order to thoroughly examine the potential for workload demands that might lead to operator overload.

Is it possible, within the operational context, to adequately define "mental" workload? What workload measures provide adequate assessment of operator workload in operational contexts? Many studies have attempted to answer these questions. Most have been restricted to a laboratory setting but a few have been applied in the "real" world. The following sections review the concept of mental workload, models of human performance with an emphasis on cognition, and a review of the metrics that have shown the most promise in assessing workload in operational environments. Finally, the theoretical justification and goals of the present study will be delineated.

Definition of Mental Workload. When the concept of mental workload first appeared in the fifties, it was viewed as similar to physical workload. Successful measurement of physical workload invited the same treatment of mental workload. As a result, the emphasis was on the quantification of workload rather than elaborating theoretical models. Unfortunately, while physical workload is readily observable, mental workload often must be inferred. This point is perhaps best made by Sanders (1979): "In discussing what 'we know' about mental load in general and methods

of measurement and assessment in particular it should be clear from the very start that we are dealing with a concept which is defined in common sense terms. Intuitively, mental load is related to the extent one is 'mentally occupied' and to the effects of this occupation on the human organism"(p. 42).

Intuitively defined concepts have a tendency to reflect the biases of the individuals doing the conceptualization. As a result, various researchers view different components of mental workload as most important. Such elements of mental workload might include input load, environmental stressors, emotions, task performance, physiological state, and operator effort to name a few.

Many researchers view the intensity of effort expended by the operator as the most important component of mental workload (Jex and Clement, 1979; Hamilton, 1979; Kahneman, 1973; Rouse, 1979; Sanders, 1979; Aasman et al, 1987). Others have focused on the human's limited processing resources ranging from the early concepts of undifferentiated capacity (Moray, 1967; Kahneman, 1973; Norman and Bobrow, 1975) to more recent multiple-resource models of attentional allocation (Freidman and Polson, 1981; Navon and Gopher, 1979; Wickens, 1980, 1984).

It is now generally agreed that mental workload is multi-dimensional in nature and, while there is no universally accepted definition, mental workload can be conceptualized as the interaction between the structure of systems and tasks on one hand and the capabilities, motivation, and state of the human on the other (Gopher and Donchin, 1986; Moray, 1989; Wickens and Kramer,

1985; Kramer, in press). Put more succinctly, it is the "cost" incurred by the operator while performing one task in terms of a reduction in ability or capacity to perform other tasks.

A Model of Human Performance. When issues concerning mental workload were initially examined in the fifties, the dominant construct was that of channel capacity. An operator undergoing maximal load was considered to be at the limit of his capacity. The human operator was envisioned as a communication channel with limited, yet constant, capacity (Attneave, 1959). This capacity was independent of the type of processing involved. Overload happened when the information to be processed exceeded maximum levels transmittable by the operator. This approach failed mainly because operators occasionally could exceed their maximum transmission rates. In fact, in some cases, operators appeared to have unlimited channel capacity - especially where practice was a factor.

Another model also posited constant capacity limits but included the notion of a limited capacity processor similar to the CPU in a digital computer. On this view, capacity is determined by a common pool of resources available to various internal processes and concurrent activities. If more than one task is being performed, operators must develop strategies for allocating these limited resources towards the processing of one of the other tasks (Moray, 1967). For these models, capacity for dual task performance is depleted, to a certain degree, by the processing required to develop new strategies, an internal space limitation, or by time

limitations, since capacity can be related to the time it takes to perform various activities. One of the major problems with this concept is that it is difficult to determine how much capacity is still available at any given time. Dual task performance, under these models, assumes that more internal programing is required to alter strategies but sheds little light on remaining capacity. In any event, time and internal space limitations in these concepts ignore the point that the processing mechanisms may have their own capacities (Sanders, 1979).

Structural mechanisms such as encoding and response selection were important components in the above models. Functional mechanisms or other components such as arousal also play a role in information processing. The recognition that effort (i.e. attention) is a component of mental workload has been a significant factor in the development of more recent models of human performance. Kahneman (1973) advanced the idea that an operator's limited ability to perform two or more functions at the same time is directly related to limited attentional resources. Kahneman's theory has three main elements: 1) the total amount of effort is limited, 2) the amount of effort required is mainly determined by the task and 3) the state of the operator (i.e. amount of practice, motivation, fatigue etc.).

The notion of processing limits was expanded by Norman and Bobrow (1975) to include the idea of data-limited performance. In this case, a task is limited not by the resources invested but by the quality of the data; straining to see through fog does not

improve what is seen. Sensory or memory limitations can affect performance no matter how much effort or other residual capacity remains. Figure 1 shows a hypothetical performance-resource function that demonstrates the relationship described above.

Another idea advanced at about this time was the distinction between automatic and controlled processing (Shiffrin and Schneider, 1977). Automatic processing does not require input from this undifferentiated pool of resources whereas controlled processing does. In other words, automatic processing is characterized by rapid parallel search and enhanced by practice, while controlled processing is slower and attention demanding. From the perspective of mental workload, those processes involving controlled processing are more applicable.

The single-capacity undifferentiated view of resources was criticized by Navon and Gopher (1979). In their words: "The central capacity notion cannot withstand the finding that when the performance of a certain task is disrupted more than the performance of another one by pairing either of them with a third one, it is nevertheless disrupted less by a fourth one." This statement recognizes the likelihood that multiple pools of resources exist and develops the idea that secondary-task techniques can be utilized to assess resource allocation.

Before moving to the multiple resource model, a few words on secondary task measurement techniques are in order. The secondary task technique requires the concurrent performance of two tasks with the performance of one task having priority over the other.

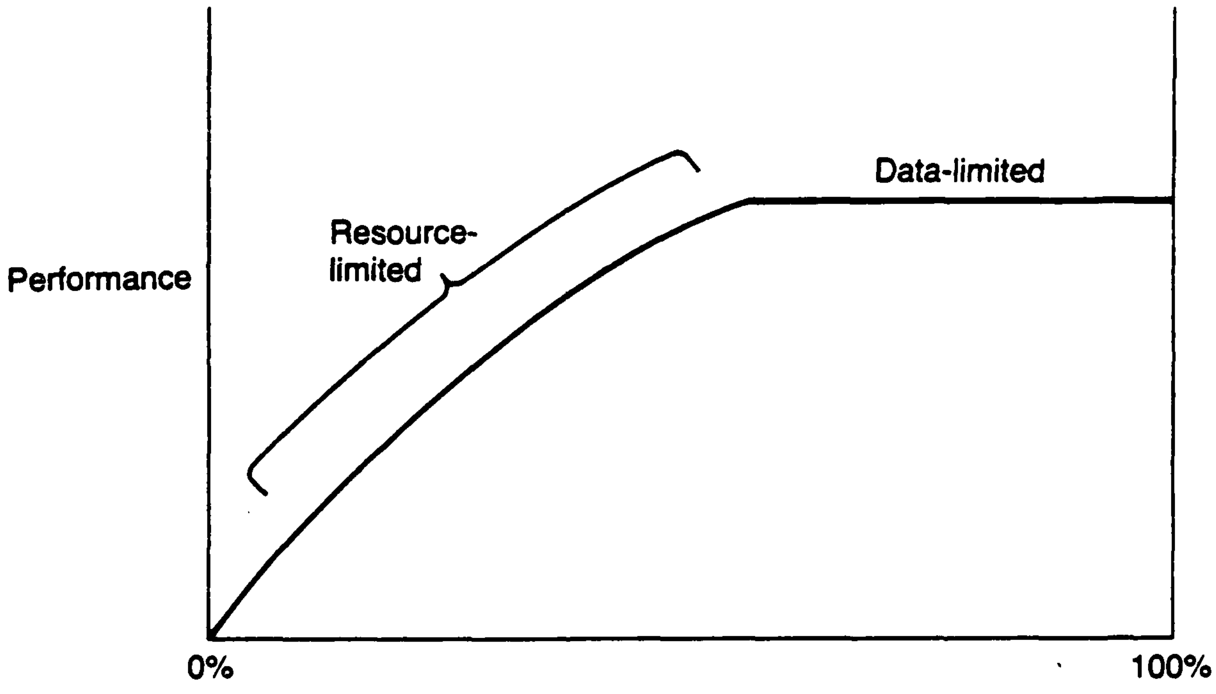


Figure 1. A hypothetical performance-resource function (from Norman and Bobrow, 1975).

Changes in performance of either task, but particularly decrements in secondary task performance, gives support to the ideas that resources are limited and competition for these limited resources occurs between the primary and secondary tasks. The most troubling aspect of the secondary task technique, in operational settings, is that of intrusion. That is, minimizing the effects of the secondary task on the performance of the primary task. Another problem is the assumption of task regularity; it is assumed that the attentional demands of the primary task are uniform throughout the analysis period. If this is not the case, workload can exceed human limitations and go undetected. The findings that certain secondary tasks interfered differentially with various primary tasks led Navon and Gopher to ponder the possibility of multiple resources in information processing. For example, vocal responses were found to interfere more than spatial responses with recall of a sentence and auditory presentation of a word impaired shadowing a message presented orally more than the visual presentation of a word. There are several variations of multiple-resource models including those that define resources as related to cerebral hemispheres (Freidman and Polson, 1981; Polson and Freidman, 1988), and distance in functional cerebral space (Kinsbourne and Hicks, 1978) among others. A multiple-resource model that has proven useful in a variety of contexts has been proposed by Wickens (1980, 1984). This model separates processing into three dichotomous dimensions, each level of a dimension representing a separate pool of resources . They include stages of processing (e.g. perceptual

vs. central and response), modalities of input and output (visual vs. auditory inputs and verbal vs. manual outputs), and codes of processing (e.g. verbal vs. spatial) (see Figure 2). Wickens (1980) determined that time-sharing two tasks was least efficient when both tasks demanded the same resource. Cross-modal (auditory-visual) presentation was more efficient than inter-modal (visual-visual). This was confirmed in a dual-task experiment featuring a continuous response task and a discrete response task (Wickens, Sandry, and Vidulich, 1983) and when interference between two discrete response tasks were compared (Damos and Lyall, 1986). Similar conclusions were drawn for the other dimensions of the model. Wickens (1984), however, cautions that the " three dimensions of the multiple-resource model do not intend to account for all structural influences on dual-task performance and time-sharing efficiency. Instead, they indicate three major dichotomies that can account for a reasonably large portion of these influences and can be readily used by the system designer. In this sense, the model is an effort to gain usability and parsimony by sacrificing some degree of precision". It is in this context that the present study will apply the multiple-resource model proposed by Wickens.

Subjective Measures. Subjective workload assessment techniques are used to obtain the opinions, feelings, and evaluations of the operator. Subjective techniques come in two broad classes: (1) questionnaires and interviews and (2) rating scales. Questionnaires and interviews can provide useful information on specific workload problems but are relatively time-

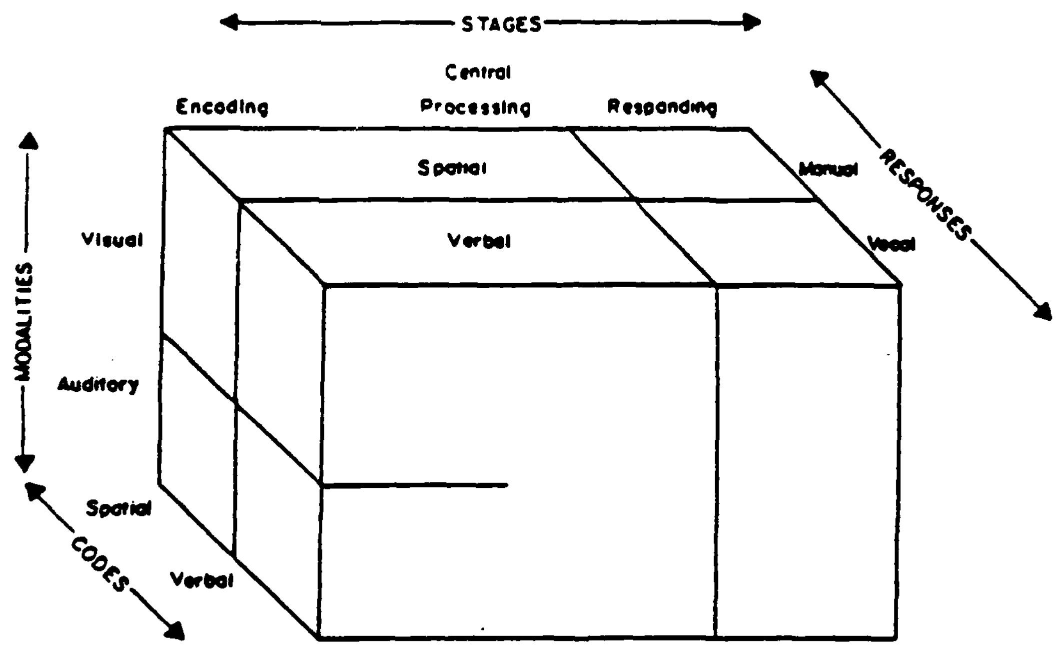


Figure 2. Wickens' Multiple Resource Model (from Wickens, 1984).

consuming and require careful formulation and well-crafted questions. If this is not attended to vast quantities of useless data can result.

The most commonly used subjective measures involve the use of rating scales (Allen and Yen, 1979). A scale is an organized set of measurements which has nominal, ordinal, interval or ratio properties depending on how it is developed. Rating scales also exhibit dimensionality, that is, an indication of what specific property the scale is intended to measure. Unidimensional scales provide a global workload rating implying that a single attribute of workload can be identified and rated. Multidimensional scales measure more than one dimension at a time and also require that the workload components being rated also be clearly identified.

Many rating scales have been developed in the aviation community for the measurement of pilot workload. Probably the most widely used is the Cooper-Harper scale (Cooper and Harper, 1969) developed for pilots to rate aircraft handling and control capabilities. This ten point unidimensional scale results in a global rating on an ordinal scale of an aircraft's performance characteristics. Variations of this scale, such as the Modified Cooper-Harper (Wierwille and Casali, 1983), have shown good applicability in workload assessment where perceptual, mediational, and communication activity is present.

The recognition of the complexity of mental workload led the Human Performance Group at NASA-Ames to develop rating scales that were multidimensional. The NASA-Task Load Index (NASA-TLX), is a

shorter, more refined version of the earlier NASA-Bipolar scales using six dimensions:

- mental demand	- performance
- effort	- physical demand
- frustration	- temporal demand

A number of factors were considered in the design of the NASA-TLX including applicability of dimensions, sensitivity and independence between dimensions, individual concepts of workload, and ease of use. TLX has been proven to be a valid, reliable, and sensitive technique for workload assessment (Hart and Staveland, 1988) and is the procedure of choice in the present study.

Performance Measures. The use of performance measures or primary task measures as indicators of operator mental workload is based on the idea that as mental workload increases optimal performance may be degraded or altered in some fashion. Such changes, then, can be used to infer the degree to which mental load has also been affected. This is the main assumption in the use of performance measures as metrics of mental workload. Performance measures were not considered as very diagnostic indicators of workload in the early years of mental workload research because it was assumed that operators could adapt to changes and maintain performance at constant levels. A more detailed look at how the operator was adapting, by possibly changing strategies, revealed that other performance measures, besides system output, could be used to detect strategy shifts and thus provide a measure of mental workload (Williges and Wierwille, 1979).

The point is that emphasis should be placed on measures that indicate strategy changes. In a multiple-task environment, such as an aircraft cockpit or simulator, many sub-tasks, besides the obvious mission completion, are involved and can be used as measures of mental workload. For example; a pilot might successfully fly a complex mission but if large control deviations or increased shedding of subsidiary tasks occurs this indicates that some type of strategy change is involved. In a simulated flight task that emphasized communication load this point was demonstrated by Wierwille and Casali (1983) who found that primary-task measures related to aircraft control did not discriminate different communication loads, whereas primary-tasks that directly reflected instructed performance on the communication task were most discriminating. By providing a more complete picture of the man-machine system, performance measures allow better insight into operator mental workload.

Physiological Measures of Mental Workload. Since workload is generally agreed to be multidimensional in nature a multi-level approach toward workload measurement has been undertaken by many researchers. As previously discussed, subjective techniques and performance measures each contribute to an understanding of mental workload. Physiological measures can further augment our understanding because, as has been implied, no single workload metric is likely to uncover all aspects of mental workload.

In the case of physiological measures, the same variation along the dimensions of diagnosticity, sensitivity, intrusiveness,

reliability and applicability apply as in subjective and performance measures. One question that always arises when physiological measures are being considered for workload measurement is why, given that physiological metrics generally incur high costs, require technical expertise during interpretation, and suffer from low signal/noise ratios, they should be used at all?

Physiological measures offer several advantages: (1) intrusiveness into primary task performance is low, (2) overt performance is not required to obtain useful insights into operator strategies and workload, (3) sensitivity to central and peripheral nervous system functions can provide unique insights into the multidimensional nature of workload, (4) some measures are quite sensitive to specific cognitive activity and (5) most measures can be applied across a wide variety of tasks.

Physiological measures are normally used to detect and reflect the functioning of the central nervous system (CNS) or the peripheral nervous system (PNS). The CNS is made up of all nerve components within the bony structures of the skull and spinal column including the brain, brain stem, and spinal cord. The (PNS) consists of all nerve pathways outside of the skull and spinal column and is further subdivided into the autonomic and somatic nervous systems. The somatic system innervates all voluntary or striated muscles.

The autonomic nervous system (ANS) has two components: (1) the sympathetic nervous system (SNS), responsible for activating body

systems during emergencies, and (2) the parasympathetic nervous system (PNS) which serves to maintain body system function. The SNS can act over relatively long periods while PNS functions are of generally short duration. These two systems most often act in conjunction but usually in a reciprocal fashion. As a result, their actions are often difficult to distinguish. Measures of interest in this study are ANS measures of cardiovascular activity.

Cardiovascular Measures. The use of heart rate measures in workload assessment has often centered on the assessment of effort (Aasman et al., 1987); with increased processing requiring greater effort and increased physiological cost. The electrocardiogram (ECG) is the instrument of choice in most studies. To measure effort, two derivatives of the ECG are often used. The first, heart rate, is calculated from the number of R waves per unit time, while the second, mean interbeat interval (IBI), gauges the average R-R interval. Both heart rate (HR) and heart rate variability (HRV) have been used to evaluate workload (Kalsbeek and Ettema, 1963; Opmeer, 1973; Aasman et al. 1987). The association between HR and HRV is not high which suggests that different mechanisms are involved. One study (Van Dellen, Aasman, Mulder, and Mulder, 1985) concluded that the variation coefficient of IBI time in msec was the best statistic in the time domain. Unfortunately, it is much too global a measure. Variability in IBI values can be subjected to spectral analysis techniques resulting in a power frequency spectrum (Mulder et al., 1973; Porges, 1984). With approximately five minutes of data, three frequency bands can be observed: (1)

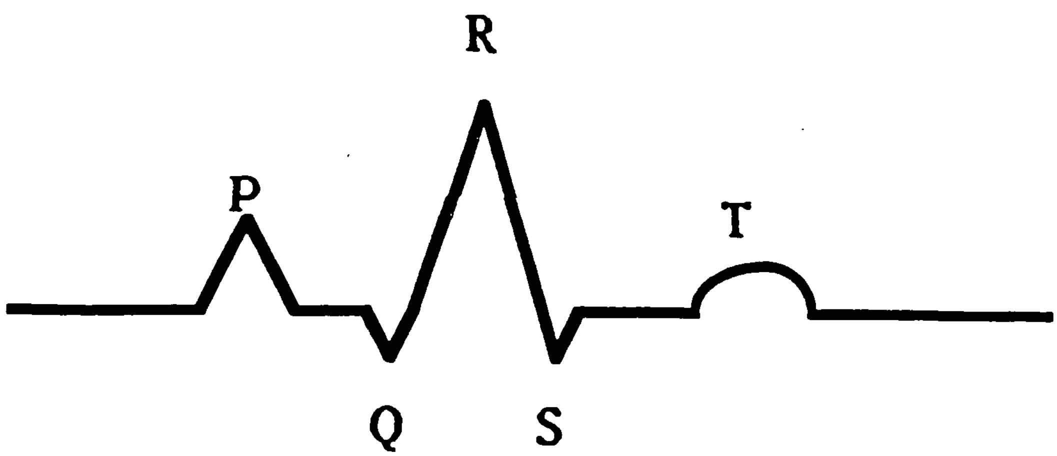


Figure 3. Prototypical electrocardiographic (ECG) trace

low-frequency, 0.02 - 0.06 Hz (vasomotor activity responsible for temperature regulation and slow trends in heart rate), (2) mid-frequency, 0.07 - 0.14 Hz (mechanisms involved in short-term regulation of arterial pressure), and (3) high-frequency, 0.15 - 0.50 Hz (effects of respiratory activity) (Aasman et al., 1987).

The 0.10 Hz component, the mid-point of the intermediate frequency band, has been extensively studied by a number of researchers (Mulder and Mulder, 1980, 1981b; Aasman et al., 1987; Vincente et al., 1987; Aasman, 1988; Sirevaag et al., 1988). The amplitude of this component has been shown to decrease with greater investment of effort. Mulder claims that the 0.10 Hz component is sensitive to increased task complexity and can be explained by two factors: 1) habituation to the environment and 2) the amount of controlled processing demanded by the task.

Sympathetic nervous system influence on the ECG is assumed to be an important component of mental effort (Furedy, 1987). The 0.12-0.40 Hz frequency band has been indicated as reflecting respiratory sinus arrythmia and as a measure of vagal influence on the heart (Porges, 1984). Referred to as V-hat, because of its association to vagal influence on the heart, decreased power in this frequency band also has been related to increased cognitive load (Sirevaag et al., 1988).

Furedy (1987) has suggested that the amplitude of the T-wave component of the ECG may also indicate SNS influence. He states, "The sympathetic index assumption is that transient changes in TWA produced by manipulations of the type used in psychophysiological

experiments reflect primarily ventricular sympathetic nervous system influences, so that TWA ... is an adequate, though not perfect, SNS index". Obviously, no single cardiovascular metric can measure all aspects of workload, but if carefully applied they can provide useful insight into human performance.

In conclusion, since mental workload is multidimensional in nature, no single-capacity model of human performance is appropriate to account for the many factors that define mental workload. Wickens' (1980, 1984) multiple resource model is the most detailed available to explain the pattern of performance interactions observed when operators are required to do a number of tasks concurrently. This is especially true in the operational environment where the present study takes place. Because mental workload assessment is so complex, and because there is no single agreed upon metric of mental workload, the application of several types of workload metrics is likely to provide the most insight into actual operator mental workload. The overall goal of the present study was to determine whether a new cockpit design could be used by a human operator. In other words, to determine what the operator workload levels were and identify areas of overload. The concern was not the effectiveness of one particular technique but, rather, a comprehensive evaluation of mental workload in this applied setting. Consequently, a comparison of the results from the NASA-TLX subjective rating scale, performance measures, and physiological metrics (T-wave amplitude, heart rate and sinus arrythmia) was judged to be the best approach in this assessment.

In this way, the multidimensional aspect of mental workload is accounted for and a realistic assessment of system demands is accomplished.

The Current Study

This study was conducted to determine how varying degrees of communication demands effect a pilot's workload and his resulting performance in a new-concept high-fidelity helicopter cockpit simulator. The purpose of this assessment was to verify that the aircraft could be successfully flown by human operators. Results of this type of assessment have a direct bearing on decisions relating to full-scale development of the aircraft being studied.

This experiment was designed so that two different missions would be flown by the pilots. One mission was designated as Intermediate and the other as Difficult. Each mission started with an easy segment followed by a difficult or higher workload segment and ended with an easy segment. The intent was for each of the segments of the mission to impose higher levels of demand on the pilots than the initial and final segments. Further, the Intermediate middle segment was intended to impose fewer demands than the Difficult middle segment. This design allowed for the evaluation of workload manipulations both within and between the two missions.

Workload assessment was based on performance data recorded directly from the simulator, NASA-TLX subjective measures collected after each mission, video-tape data recorded during mission performance, and ECG data recorded on-line during the mission.

METHOD

Apparatus

The study was conducted in a full-scale, fixed base, high-fidelity helicopter simulator featuring a new cockpit design. Performance data from the simulator was sampled every 80 msec for the duration of each mission and stored on nine-track magnetic tape. Each of the performance measures was provided with a time stamp equal to the resolution of the simulator update, 30 msec. Two standard VHS video-cameras were used; one provided a view of the pilot's head and face, another was mounted behind the pilot and provided a heads-up outside view.

A close-up view of two multifunction displays was also provided on the quad-screen view. An audio track of the video-tape recorded all incoming and outgoing communication. ECG was recorded using three pre-gelled, sintered silver chloride electrocardiogram (ECG) electrodes, manufactured by Med Associates. The initial heart-rate signal was then amplified to approximately one volt by a double FM transmitter system designed in-house. The telemetry equipment then converted these voltage oscillations into a radio signal coupled to a scanner-receiver at a PC-workstation. The receiver output a time-varying voltage analog signal which was band-pass filtered (10 - 100 Hz) and converted from analog to digital form on a National Instruments AT-MIO-16-H9 that was connected to a Dell 310 microcomputer. The PC then recorded the ECG to disc and to a back-up tape system. The simulator also presented a synch pulse (time stamp) every 30 msec to the PC based

performance/workload station.

Subjects

Six male pilots took part in the experiment, four military helicopter pilots and two civilian helicopter pilots. All subjects possessed normal or corrected-to-normal vision. All subjects were between 30 and 45 years of age. Flight experience ranged from 2000 and 5000 hours.

Design

Two missions, of approximately 30 minute duration, were flown by each pilot. An abstract time line of the missions is as follows:

Mission 1:	Easy portion - (7 min)	Difficult portion - (16 min)	Easy portion (7 min)
Mission 2:	Easy portion - (7 min)	Difficult portion - (16 min)	Easy portion (7 min)

Two different "Easy" mission segments were implemented in the simulator. One "Easy" segment was paired with the "Difficult" mission for three of the pilots and with the "Intermediate" mission for the other three pilots. The other "Easy" segment was also paired with the "Difficult" mission for three of the pilots and with the"Intermediate" mission for the other three pilots. This allowed the same amount of practice on the Easy segments for both the "Difficult" and "Intermediate" missions. Also, counterbalancing, where one easy segment is performed with the difficult mission by half of the pilots and with the intermediate mission by the other half of the pilots and vice versa for the

other easy mission segment, was required to unambiguously interpret the data.

Half of the pilots performed the "Intermediate" mission first and then the "Difficult" mission and the other half of the pilots performed the missions in reverse order.

Experimental Task

Each pilot arrived at the simulator with sufficient time to undergo a prebriefing before each mission. The exact details of Mission A (Mission 1) and Mission B (Mission 2) are included in Appendix A (for Mission A) and Appendix B (for Mission B). The pilots flew both missions on the same day.

Both missions were set up as reconnaissance flights consisting of two aircraft that were designated a Scout Weapons Team (SWT). During each mission, the airspace covered by the SWT was divided into two sectors. One area was the responsibility of the simulator pilot while his wingman covered the other portion of the designated airspace. The simulator pilot was designated the team leader while his wingman operated beyond visual range. The wingman was actually a simulator technician following the mission script and in contact with the simulator pilot via headset or radio communications.

The goal of the mission was to establish a predetermined Screen Line. A Screen Line is the forward position of a reconnaissance team that results in a buffer zone, free of threats, between the team and the main ground force. The pre-mission briefing directed the pilots to report all threat sightings and to identify any obstructions of roads and bridges in their area during

the flight. Threat contacts were to be verbally reported to the pilot's wingman and ground units in the area. The pilots were to navigate through their designated area by following a series of navigational waypoints. These waypoints are detailed in Tables I and II and can be referenced to the appropriate maps (Mission A or B) contained in appendices A and B.

Table I

Mission A Waypoints

Waypoint	Grid	Physical Description
A	UV 0909	Mission Start
B	UV 0907	SW Corner Lake
C	UV 0806	RR Station
D	UV 0604	Wire Tower
E	UV 0505	Church Steeple
F	UV 0306	RR Station
G	UV 0205	Red Barn
I	UV 0504	RR/Rd Intersection
K	UV 0005	Road Intersection

Table II

Mission B Waypoints

Waypoint	Grid	Physical Description
A	UU 1208	Mission Start
B	UU 1209	Building in Town
C	UU 1309	Red Barn
D	UU 1411	Wire Tower
E	UU 1312	Wire Tower
F	UU 1214	Red Barn
G	UU 1215	Wire Tower
H	UU 1315	River Intersection
I	UU 1513	Wire Tower

The pilots were to establish a flight path by navigating to each waypoint in succession (A then B then C etc). Pilots were directed to report their arrival at a waypoint/phaseline as well as their crossing times. Pilots were also asked to report on fuel level status at specific moments during both missions.

To vary communication demands during the missions a number of manipulations were employed. The portion of the flight path that consisted of the first and last few waypoints in each mission were designed as the Easy segments. These segments placed little if any communications load on the pilots due to an absence of threat conditions. The Intermediate segment of Mission A consisted of the middle waypoints in the flight path. Communication load increased since threat forces were encountered in this portion of the flight. When the pilots flew the middle section of Mission B, they were verbally instructed to navigate to a new map coordinate, not included in the pre-flight briefing, and directed to report threat sightings and other details of interest in this new area. The unexpected nature of this mission deviation was expected to increase the pilots' communication workload with respect to the middle segment of Mission A (Intermediate segment). This portion of Mission B was designated the Difficult segment.

Procedure

Due to limitations of simulator availability, practice on the mission profiles was restricted to time actually spent flying each mission. However, all of the pilots' experience levels were approximately equal both in actual flying and simulator time. It

was felt that since every pilot had to begin each mission with an Easy segment practice effects would be equal.

The pilots were fitted with three ECG electrodes, seated in the simulator cockpit and connected to the telemetry equipment. Before each mission, several minutes were used to calibrate the equipment and to ensure the system was functioning properly. The pilots then flew the mission during which performance measures were recorded by the simulator. Total mission duration varied from 23 minutes to 54 minutes.

<u>Performance Measures.</u> The performance measures recorded in the simulator are listed in Table III.

Table III

<u>Simulator Performance Data</u>

Elapsed Mission Time	Altitude
Mission Waypoint	Roll
Object Collision Indicator	Pitch
Ground Collision Indicator	Yaw
Message Indicator	Sideslip
Simulator X-Coordinate	Longitudinal Stick Position
Simulator Y-Coordinate	Collective Position
Torque	Pedal Position

These data were sampled every 80 msec for the duration of each

mission and recorded onto the nine-track magnetic tapes. The data was then analyzed to determine task-dependent measures of pilot performance.

In addition to the data from the simulator, a composite videotape, produced from the cameras in the cockpit, was used to provide additional performance measures. This videotape displayed four panels on the monitor at the same time. The upper left-hand corner displayed a view of the pilot's head and face. This was used to measure head and eye movements in an effort to establish visual scanning patterns and strategies used by the pilots. The top-right panel was a view from behind the pilots head and provided an outside the cockpit view. This provided information on aircraft orientation, control, ground contact and tree strikes. The bottom two panels contained instrument displays and were used to assess communication activities, radio frequency changes, and waypoint passages.

The videotape also contained subject and mission identifiers and elapsed time. This was used to relate performance data on the nine-track magnetic tapes with information from the videotape.

An audio track of the videotape recorded all incoming and outgoing radio transmissions. Audio information enabled us to perform an analysis of the communication tasks involved in the mission such as fuel status reports, waypoint passage and threat identification.

Videotape analysis was done on a minute by minute basis and required three separate passes. Frequency and timing of each head

and eye movement were recorded as well as any other mission related activity. Coding sheets obtained for each pilot and mission are presented in Appendix C. Running sums of the total number of ground queries for information (Q) were obtained as well as the total number of responses to queries (TR). A query (Q) was a radio transmission made to the pilot that required an audio response. Also included were timely responses to queries elicited within 10 seconds (R) and responses occurring 10 to 60 seconds following a query, designated Long Responses (LR).

Duration and frequency of Eye movements (EM) and Head movements (HM) along with Total movement (TM) time were also obtained. This TM category, the sum of the EM and HM times, is a measure of the total time spent scanning cockpit instrumentation.

Error categories derived from the video tape included ground contact (GCXT) and tree strikes (TCXT) as well as task shedding (TS). The TS category included such subcategories as failure to provide a timely spot report (TSSPTRPT), situation report (TSSITRPT), response to a query with a latency less than 60 seconds, or report of waypoint passage.

The raw measures output by the simulator and those derived from the video tape analysis were grouped into categories reflecting more global aspects of pilot performance . These collapsed measures indexed pilot communications, aircraft control activity, instrument scanning and performance breakdowns and were computed for each minute of each mission. Appendix D contains the plots of these four collapsed categories for each pilot and

mission.

The global communication measure included measures of frequency of correct messages initiated by the pilot, timely responses to queries (R), and long responses (LR) to queries. The global scanning measure was derived from the variables containing the frequency and duration of head and eye movements and total instrument scanning time. Large values indicate that the pilot was spending long periods of time looking at the instruments (e.g. head-down).

The global control measure was arrived at by using the standard deviation of the yaw, pitch, roll and sideslip variables. These measures were combined (see Appendix E for general procedures) with the estimates of the average velocity of the stick and collective movements to provide the final collapsed aircraft control measure.

The global error measure, was obtained using communication error measures from the videotape analysis and flight control errors. Communication errors were those where task shedding occurred or where long responses or failure to respond to queries took place. Flight control errors included frequency of ground strikes, total time in contact with an object, and total time above the maximum allowable altitude (30 feet).

<u>Electrocardiographic Measures.</u> ECG data was recorded the entire time the pilots flew each mission. The heart signal from each subject was transmitted to the PC work-station by way of the telemetry system, filtered, digitized and written to the disc of

the Dell 310 microcomputer. This data was then interpolated off-line for R-wave detection, heart rate, interbeat interval, and T-wave amplitude. Next, the data were smoothed and entered into a program for Fast Fourier Transform analysis. This program provided the power of the signal from 0 to 0.6 Hz as its output with a resolution of .01 Hz. The programs required to perform this interpolation are included in Appendix F. Following the use of these programs, it was then possible to subject the three major frequency bands to statistical analysis.

Subjective Measure. After each mission, subjects were required to make subjective ratings using the NASA TLX scales. Pilots rated, on a scale of 1-10, mental effort, physical effort, time pressure, fatigue, frustration, and performance level required at each waypoint. A card-sorting technique was employed to evaluate which of these components of workload were felt to be of particular importance to individual pilots and a weighted global subjective workload score was also produced.

RESULTS

Performance Measures

The global performance measures for Mission A (Figure 4), Mission B (Figure 5), and Missions A and B combined (Figure 6) did not show any significant differences between Mission A and Mission B. Measures of communication, aircraft control, scanning patterns, and performance errors were not significantly different for Missions A and B.

There were some differences between the middle segments and the beginning and ending segments within each mission. The middle segments were designed to impose higher demands on the pilots and this was reflected in increased pilot communication and more time spent scanning cockpit instrumentation. Aircraft control and error measures did not differ as a function of mission phase. Both Mission A and B showed the same changes across waypoints.

Since each pilot used slightly different strategies when flying the missions, mission length varied considerably (from 23 - 54 minutes). As a result, none of the mission segments could be compared in their original format. To facilitate further analysis, five minute segments were identified that reflected periods of high control, high communication, high instrument scanning, and a baseline where these value were low. This was done for each pilot and mission for each of the global measures.

Using the scores from the four global measures on a minute by minute basis and averaged as a function of waypoint for each of the six pilots and Mission A and B combined, a correlational analysis

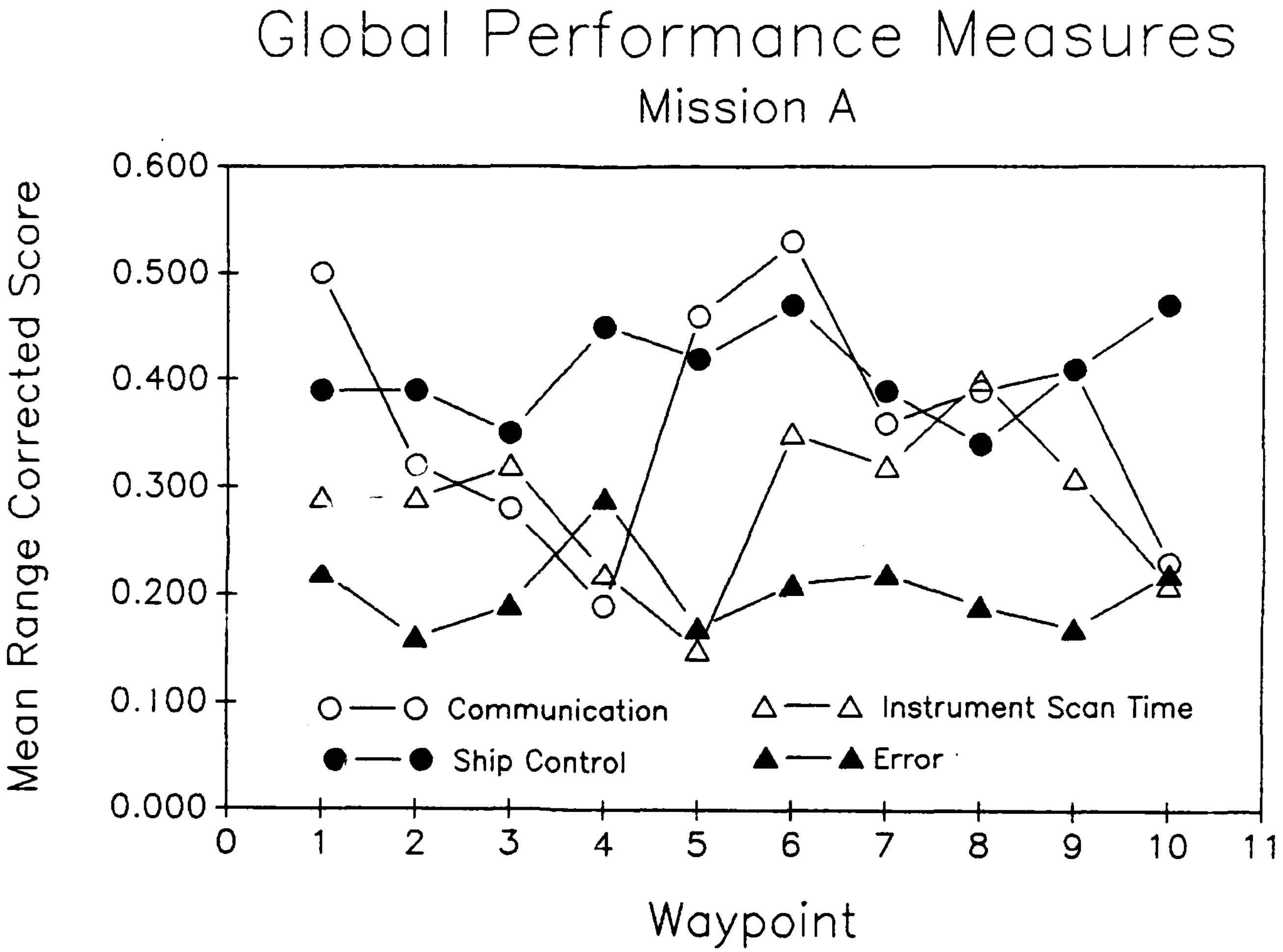
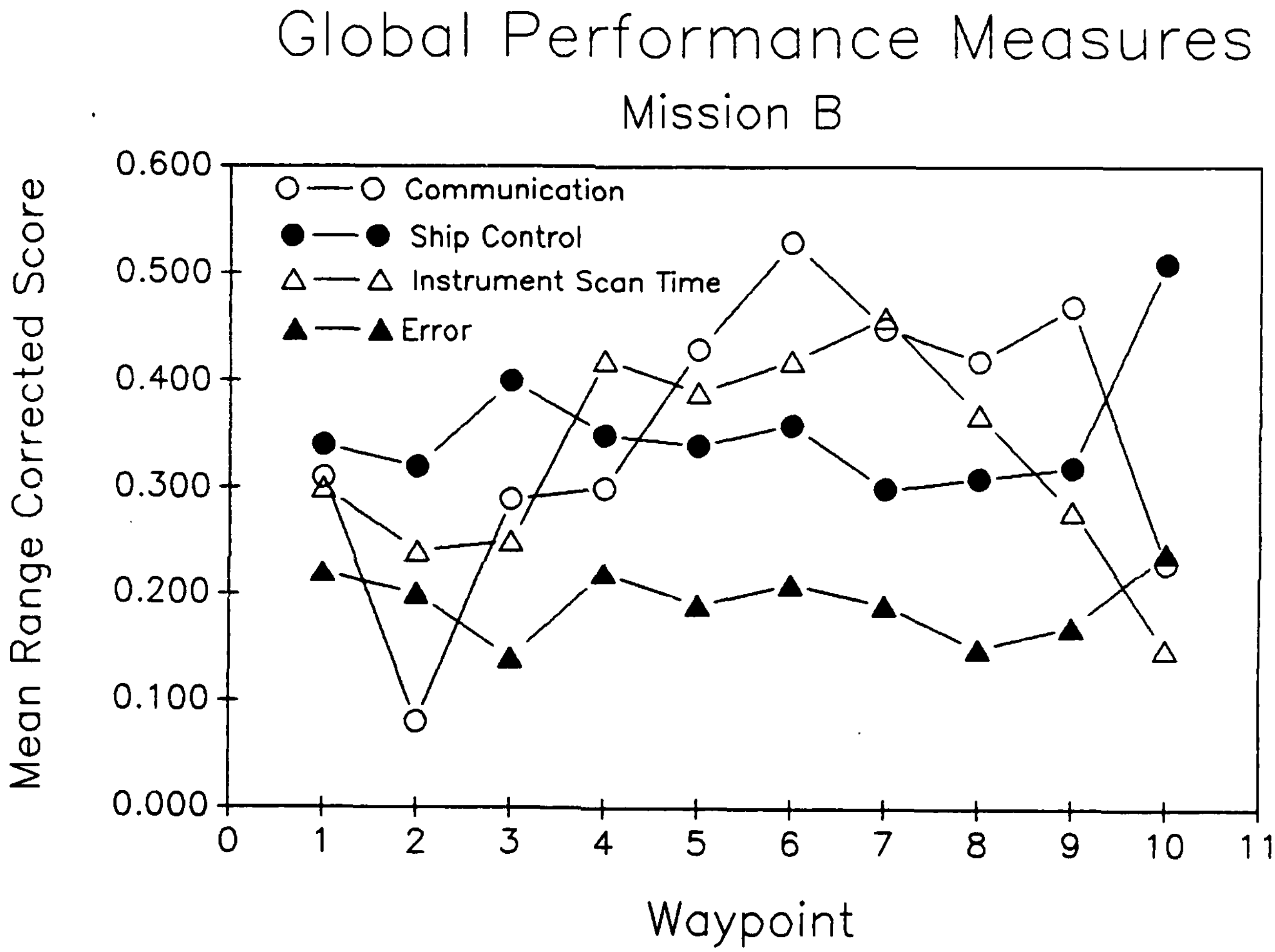
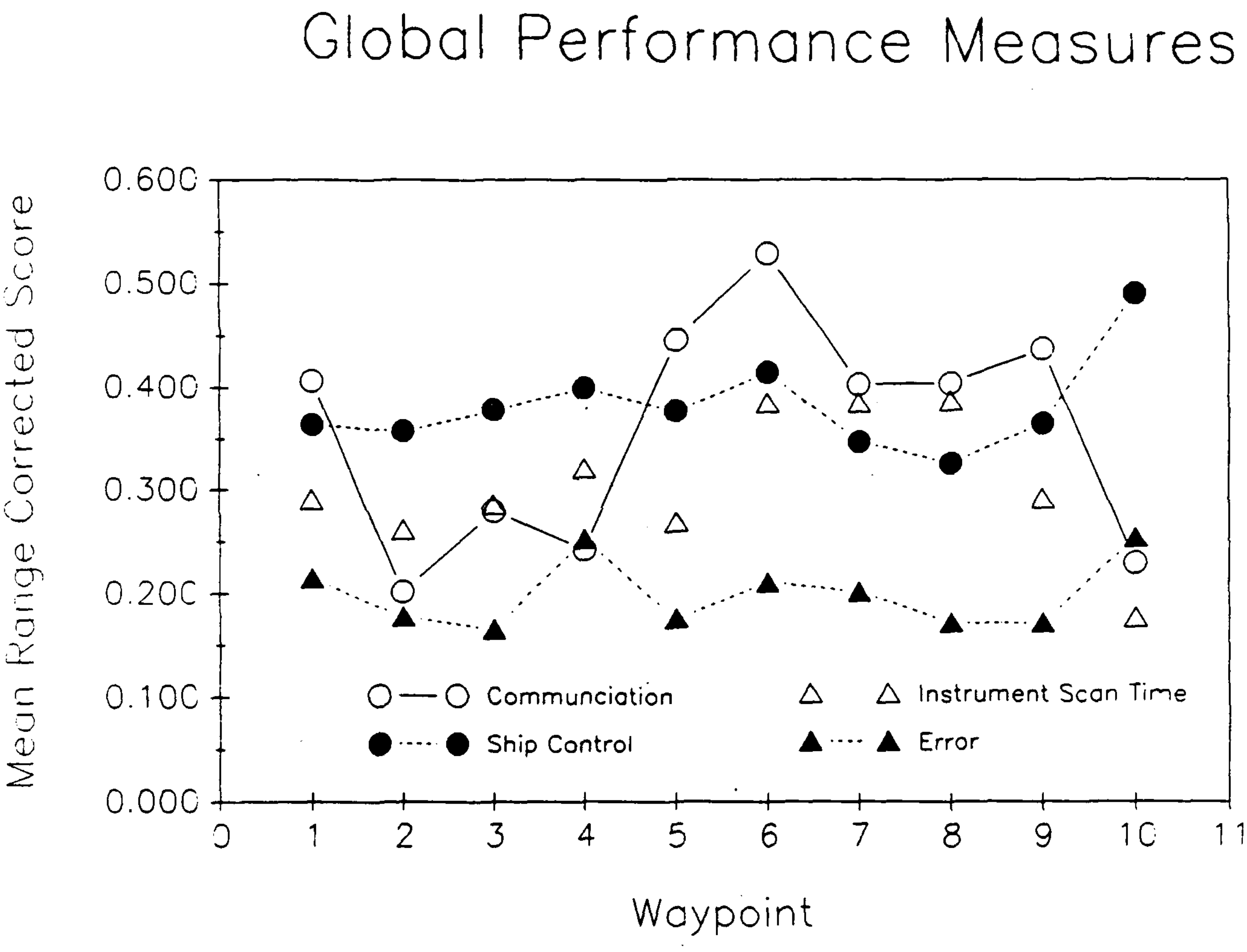


Figure 4. Global performance measures for Mission A.



<u>Figure 5</u>. Global performance measures for Mission B.



<u>Figure 6</u>. **Global performance measures for Mission A and Mission B combined.**

was performed. The resulting correlation matrix, presented in Table IV, indicates the relationship between the measures of communication, control, scanning, and error.

Table IV

Correlation Matrix for Global Measures

	Control	Scan	Error
Communication	-.11*	.24*	-.01
Control	--	-.25*	.24*
Scan	--	--	-.05

(* = statistical significance at $\underline{p}<.05$)

(N = 6)

Four statistically significant correlations were obtained. When communication values were high, control values were low ($\underline{R}$ = -.11). This indicates that as the pilot was required to communicate more frequently, control of the helicopter decreased. This relationship was also identified for the control and instrument scanning measures ($\underline{R}$ = -.25). When their heads were down scanning instruments flight control was reduced.

A significant positive correlation was obtained between the control and the error measure ($\underline{R}$ = .24). This signifies that with increases in flight control inputs pilots were more likely to commit errors which included ground collisions, object collisions,

and late or absent responses to queries. It is also possible that more control inputs resulted as the pilots attempted to recover from errors. A positive correlation was also obtained for the communication and scan measures (R = .24). As pilots spent increased amounts of time at communication tasks they were also spending more time scanning their instruments.

These relationships are understandable in terms of how the pilots prioritized the sub-tasks depending on the demands of the flight. As communication requirements increased during the middle, heavier workload, segments of each mission pilots spent more time heads down, on the instruments. This, in itself, would necessitate reduced aircraft control inputs since the pilots could not see where they were going. On the other hand, increased control inputs would be likely when avoiding threats or flying nap of the earth in areas where object density, such as trees, was high although this relationship was not specifically determined. While this was happening, the pilots would probably ignore or miss radio communication and be more likely to strike objects or the ground.

Subjective Measures

The NASA TLX scales were used to collect the subjective ratings from the pilots. Ratings were collected following each mission. The pilots rated six phases of each of the two missions on the following bi-polar scales: mental demand, physical demand, temporal demand, effort, performance, and frustration level. The mission phases rated were based on the transition between waypoint and included: A-D, D-F, F-G, G-H, H-I, I-end of mission.

The six ratings on each of the scales for each mission and mission phase were aggregated into global measures of subjective workload. These global subjective ratings are presented in Table V. Larger values indicate higher workload ratings.

Table V

Global Subjective Ratings

	Mission Phase					
	A-D	D-F	F-G	G-H	H-I	I-Mission End
Mission A	5.5	5.9	5.8	6.5	6.7	5.2
Mission B	5.2	5.3	5.9	6.4	6.9	5.3

The subjective measures were not significantly different in missions A and B ($p > .10$). However, the ratings did differ as a function of phase within mission ($F(6,30) = 3.0$, $p < .05$). The pilots rated the beginning and ending segments of each mission as lower in workload than the middle segments of the missions. This is consistent with the performance measures where better performance was obtained in the initial and final segments of each mission.

Electrocardiographic Measures

Aasman et al. (1987) indicated that a time period of about five minutes, during which task demands remained relatively constant, was required to successfully record and analyze ECG data. In the present study, each pilot varied in the time taken to fly each segment of each mission. Flight times for mission completion

ranged from 23 to 54 minutes. Obviously, the time from waypoint to waypoint was not the same across pilots and missions. Therefore, it was not reasonable to compare the missions as a function of waypoint.

Instead of performing a waypoint by waypoint analysis of the cardiac data, we decided to analyze five minute segments as a function of the level of communication and control demands. A baseline period of five minutes was chosen for each pilot and mission where the communication and control measures were low. Two other five minute periods were defined that reflected high demands. One was identified with high communication and low aircraft control values while the other was associated with large aircraft control values and low levels of communication.

Two of the pilots' data had to be dropped from the analysis. One pilot flew over the 30 foot maximum altitude, as defined by the nap of the earth requirement, for more than 90% of each mission. As a result, his aircraft control demands were much lower and he did not make the trade-offs between communications and control that were identified in the correlation analysis. Another pilot did not complete the mission because he got lost and crashed. Consequently, his data was incomplete and not usable.

Table VI contains the mean values of the cardiovascular measures collected from the four remaining pilots.

Table VI

Cardiovascular Measures

Measure	Condition		
	Baseline	Control	Communication
Inter-Beat-Interval (msec)	791	795	791
T-Wave Amplitude (mV)	31	37	37
0.02 - 0.06 Power	731	1145	1084
0.07 - 0.14 Power	1836	1444	2163
0.15 - 0.50 Power	818	724	848
0.10 Hz Component	602	401	722

These measures are collapsed across Missions A and B because the analysis did not indicate any significant differences as a function of Mission (p>.10).

The within mission analysis revealed that mean Inter-Beat-Interval was not influenced by the different mission segments (p>.10). Similarly, spectral power in the body temperature (0.02 - 0.06 Hz) and respiration (0.15 - 0.50 Hz) frequency ranges did not show any sensitivity to the mission segment manipulation (p>.10).

Three cardiovascular measures were found to be significant and the results are shown in Table VII.

Table VII

ANOVA Results of Cardiovascular Measures

SOURCE	F	p<
0.07 - 0.14 Power	7.11	0.05
0.10 Hz Component	4.61	0.10
T-Wave Amplitude	11.07	0.01

Power in the frequency range associated with short-term regulation of arterial blood pressure (0.07 - 0.14 Hz) was effected by mission segment, $F(2,6) = 7.11$, $p<.05$. Marginal significance, $F(2,6) = 4.61$, $p<.10$, was seen for the 0.10 Hz component of this mid-range frequency band. Since this component reflects operator effort, the observed effect would seem to be consistent with the increased demands placed on the pilots during these mission segments. Power was lower only for the control measure relative to the baseline period but higher for the communication measure.

T-wave amplitude, which reflects the influence of the sympathetic nervous system and is assumed to be an important component of mental effort, was sensitive to differences between the high load periods of control and communication and the low workload baseline period ($F(2,6) = 11.07$, $p<.01$). This sensitivity was expected but the increase in T-wave amplitude was not (Furedy, 1987). The three cardiac measures were subjected to single-df post-hoc comparisons for each of the levels. Most of the variance can be accounted for

by differences between the control and communication levels for both HRV measures (.07 - .14 Hz: $F(1,6) = 7.09$, $p<.05$; 0.10 Hz: $F(1,6) = 4.52$, $p<.10$). T-wave variance was mainly influenced by the difference between the combined high load periods and the low baseline period ($F(1,6) = 33.15$, $p<.05$).

DISCUSSION

The goal of this study was to determine the effects of various levels of communication load on a pilot's workload and mission performance in a newly designed helicopter cockpit. In other words, the study was conducted to find out, as accurately as possible, if a human operator could successfully fly the aircraft and use the communication equipment when required.

Due to the multidimensional nature of workload, no single measure could be expected to examine all aspects of workload. Further, because of the applied setting of this study, the emphasis was not on validating any particular type of metric, but rather on a comparison of the results of different measures to verify the actual pilot workload. In this respect, the study appears to have been successful.

All three types of measures used in this study, performance, subjective, and cardiovascular, showed that there was no significant difference between Missions A and B. As indicated, Mission B was designed to be more difficult than Mission A. This obviously was not the case. However, the important point here is that all three metrics were consistent in this finding.

The measures were also consistent in being able to identify the effect of the within-mission manipulations, easy segments versus difficult segments, but in slightly different ways. The subjective ratings provided a more global look at where high workload was experienced in each mission but did not give much insight into the task components or pilot strategies that were

causing this subjective feeling.

The correlation analysis of the performance measures was helpful in identifying some of the components that contributed to the pilots' subjective ratings. While the experiment was designed to generate increased demands during the middle segments of each mission, the nature of that workload was not fully realized until the performance measures were carefully explored. It seemed reasonable to expect that increased communication load would result in increased instrument scanning and thus decreased control of the aircraft, but the performance analysis confirmed this. This added sensitivity allows the applied researcher to view workload components that can remain hidden if only subjective ratings are used. Unfortunately, performance metrics also have limitations such as lack of generalizability across different types of tasks or difficulty insensitivity. Therefore, the application of physiological measures, and of particular interest to this study, cardiovascular metrics, augmented the workload information obtained by subjective ratings and performance measures.

The three cardiovascular measures that were sensitive to processing demands in this study help to complete the workload assessment. The intermediate frequency band of 0.07 - 0.14 Hz, determined in the spectral analysis, has been shown to be related to task demands. As the pilots' aircraft control demands increased, power in this spectrum decreased, confirming the association to task demands. The 0.10 Hz component of this intermediate frequency band has been demonstrated to be a reflection of the effort

expended by a subject. This was apparently the case in the present study where decrease power during the difficult mission segments is an indication that the pilots were expending greater effort to maintain performance. The effect observed was probably influenced primarily by differences between the control and communication levels (Derrick, 1988). In any case, aircraft control demands seem to have had the greatest effect and not communication load since the decrease in spectral power was observed only for the aircraft control category. The most likely explanation is that the communication demands were not great enough for these measures to detect. However, there are other possible explanations. This experiment was conducted to determine communication workload. Pilots were required to engage in verbal activity which results in large variations in respiratory activity. Most studies referenced did not involve tasks with a large amount of vocalization. Therefore, the negative results for the communication segment may be due to a respiratory confound of the spectral components. This may also account for the rise in power for the communication category. Another possibility, although less likely, is that the communication load was so great that the subjects simply could not keep up with the load and quit investing effort into the task. A decrease in T-wave amplitude during high load periods (communication and control), when compared to the baseline, was expected. Surprisingly, this was not the case. It appears that the measure was sensitive to the differences in workload, as noted previously, but the direction of the amplitude change was opposite

to what Furedy (1987) has reported. It seems unlikely that the high-load segments were actually lower in demands than baseline. There are a number of possible reasons for this finding. Furedy argues against electrode placement as effecting directionality but it is a possibility. The artifact-of-heart-rate possibility (i.e. influence of tachycardia) remains but most evidence has refuted this. A more likely possibility is that T-wave amplitude may be reflecting a respiratory artifact rather than task difficulty. This is more of a problem in studies involving higher levels of verbalization such as the present study. Reversals of direction have also been seen in studies that result in high subject heart-rates (greater than 160 beats/minute). Again, this is unlikely for the present study since subjects rarely exceeded 100 beats/min.

The measures used in this study, clearly show that the pilots were able to function within the constraints of the cockpit configuration and the mission manipulations. However, a single metric would have been inadequate to make this determination. The cardiovascular measures showed that increased effort was required to maintain performance when aircraft control load was high but were not sensitive to the communication load. At the same time, they helped identify periods when the pilots were investing more effort but where the performance measures alone were unable to discriminate this fact. In their turn, the performance metrics helped to understand the underlying components of the processing demands.

The findings can, to some degree, be explained by the Resource Model. Effort can be equated to an increased investment of resources or as a willingness to invest capacity. Aasman et al. (1987) contends that amplitude changes of 0.10 Hz component reflect the use of resource-limited mental operations. Marginal significance was observed for the 0.10 Hz component in the present study relative to the aircraft control measure. The dual-task technique was not an integral part of the experiment. As a result, it is difficult to assess specific resource dimensions of the model. However, the results do show that trade-offs occurred as task demands changed. For example, pilots would sacrifice control performance as communication and scanning demands increased, requiring more effort. The Resource Model accounts for the performance trade-offs observed here although it is equally plausible to apply Kahneman's (1973) undifferentiated-resource model here as well. As resources were required for these additional tasks, trade-offs occurred resulting in decreased performance and increased errors. However, the pilots were able to time-share resources (e.g. those responsible for visual scenery and auditory communication) well enough to perform each mission. This indicates that the required resources either came from different resource dimensions or that capacity within a dimension had not been exceeded. In either case, the data suggest that more effort was required to access the applicable resources. These aspects of the Multiple Resource Model or the undifferentiated model help to explain the underlying mechanisms of human performance.

CONCLUSION

The use of a single measure of workload is not sufficient to adequately assess workload, in all of its dimensions, in an applied situation. This study showed that the careful application of various techniques and a comparison of the results of those techniques can be used to identify areas of high workload, effort and inadequacies of design.

The design inadequacies in this case relate to the experiment itself. The communication levels were not sufficiently different between Missions A and B to cause significant differences in processing loads. In many applied settings, it is difficult to achieve a perfect experimental design.

One area of concern with respect to cardiovascular measures has to do with their applicability in experiments that involve large amounts of vocalization. While their usefulness is not to be denied, complications due to respiratory activity and speech require careful application of the measures and an experimental design that compensates for this effect.

Regardless, the use of different workload assessment techniques can provide insight into man-machine systems both in the design phase and once the system is operational.

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APPENDICES

APPENDIX A

Pre-flight Briefing for Mission A

Tactical Situation. A Squadron from the 17th CAV has been assigned by the Aviation Brigade Command to support an ATKBN which has been placed under the operational control of ground units within the 2nd Brigade. Your Air Cavalry Troop (ACT) from the squadron has been tasked with conducting zone reconaissance to the front of and along the East-West borders of the 2nd Brigade.

Mission Description. The mission given to your ACT is to perform a zone reconnaissance of the assigned area, with the goal of establishing a predetermined Screen Line, which has been depicted on your mission map. To accomplish this mission, your ACT has been divided into Scout Weapons Teams (SWT's), each of which consists of two LHX aircraft.

The area which has been assigned to your two-man SWT has been divided into two separate sectors, the Western sector which you will cover, and the Eastern sector which will be covered by the other member or your SWT, your wingman. As you complete your mission, your wingman will be operating and reporting independently beyond your visual range. However, the efforts of you and your wingman will be coordinated through mission planning and timing control of mission milestones (waypoint arrivals and departures, and phaseline crossings). You have been designated as the SWT leader, and as such should expect to be the recipient of orders from you Squadron TOC which are directed to the entire SWT.

While performing your zone reconnaissance, your instructions are to report all threat sightings to the BN S2, utilizing the available communications and reporting capabilities of your LHX aircraft. Since the roadway and bridge system in this region is considered vital to future efforts of the 2nd Brigade, maintain a flight path which allows you to assess the condition of the roads and bridges in your sector. All obstructed roads and bridges should be reported immediately to the BN S2, using the available communications and reporting capabilities of your aircraft, so that this information can be used during tactical planning for this region. The condition of passable roads and bridges does not need to be reported.

In addition to reporting threat contact to the BN S2, the appropriate ground unit(s) operating in your sector should be notified of all threat sightings and information relevant to their respective areas. Since the ground units of the 2nd Brigade possess only voice communications capability, these reports must be verbal in nature. (Note: The ground units in your sector will not be visible to you, although their boundries will be depicted on your map.) Furthermore, you are to alert your wingman as to any threat sightings which may impact the completion of his segment of the mission.

To aid in the completion of your mission, a series of checkpoints/waypoints has been established in each of the sectors for which your SWT is responsible. You are to establish your own appropriate flightpath by these waypoints which will allow you tc complete your mission. All checkpoint/phaseline crossing times should be adhered to as closely as possible, and arrivals at all

designated waypoints should be reported verbally to the Squadron TOC. Your wingman will report his checkpoint/phaseline crossings independently.

Intelligence. The security of this region is uncertain. Aggressor armored units have been observed advancing towards this area from the South, but have not yet been committed to battle and have not been observed to have assembled into a massed, unified force. As a result, sightings of small isolated units and groups of threat vehicles are possible. The Aggressor units in this region are equipped primarily with BMP's, T-72 tanks, and ZSU-23-4's. Threat sightings are expected to the South of Phaseline BLACK (your screen line), but are also possible within the boundaries of your sector.

Air-to-Air engagements during the previous 24 hours have essentially neutralized Aggressor tactical air power, although they still retain the ability to interfere with our helicopter activities. Although sightings of Aggressor helicopters (HIND/HAVOC) are not expected, they remain a possibility for which you should be prepared.

Weather. Scattered boken clouds with visibility to 50,000 feet. Wind conditions are calm.

Rules of Engagement. The mission assigned to your Squadron is to support the 2nd Brigade by conducting zone reconnaissance. Your mission is to search for, detect, and immediately report on the strength and location of threat elements while adhering to your predetermined waypoints/checkpoints. You have been cleared into this area to observe and report only, and are cleared to engage only if you have been fired upon and engagement is absolutely necessary for self defense.

Operations - Mission A

Location	Grid	Physical Landmark	Time
Mission Start Checkpoint A	UV 0909	Mission Start	
Checkpoint B	UV 0907	SW. corner Reservoir	
Checkpoint C	UV 0806	RR Station Bldg	
Checkpoint D	UV 0604	Wire Tower	
Checkpoint E	UV 0505	Church Steeple	
Checkpoint F	UV 0306	RR Station Bldg	
Checkpoint G	UV 0205	Red Barn	
Checkpoint H	UV 0504	RR/Rd Intersection	
Checkpoint I	UV 0402	Hway/River Brdg - 4 Ln (Screen Line) NLT MT = 0:18:00	
Checkpoint J	UV 0005	Road Intersection	

You will begin your mission from a low hover at Checkpoint A, having recently departed FARP01, where you were refueled with 875 lbs. of fuel. It is estimated that the return trip from your region of Phaseline BLACK to FARP01 will consume 200 lbs. of fuel. A new FARP (FARP02) is scheduled to be established in your sector which will be positioned closer to Phaseline BLACK and would require 100 lbs of fuel to reach. However, it is unclear whether FARP02 will be established in time for your use and its exact coordinates have not yet been established. To comply with existing fuel safety margins, you are instructed to report immediately to your SQDN TOC when your fuel level has reached 600 lbs. to receive orders to continue your assigned mission or to return to FARP01 at that time.

COMMUNICATIONS

FM ______		VHF ______		UHF ______		
SCOUT/ALT ______		WPN/A&L ______		LIFT/PZ ______		
SQDN ______		SCOUT ______				
RECON	_62	1.	_W_31	1.	_B	Brief/Debrief
CO	_01	2.	_W_32	2.	_I	Blues insert
TOC	_04	3.	_Y_7	3.	_G	Miss. Release
JTOC	_60	4.		4.	_D	Rations
XO	_46	5.		5.	_W	Water
P/LDR	_51	6.		6.	_L	LP/OP
P/SGT	_55	7.		7.	_M	Chg/Mission
FARP	_77					

_F	FM
_V	VHF
_U	UHF

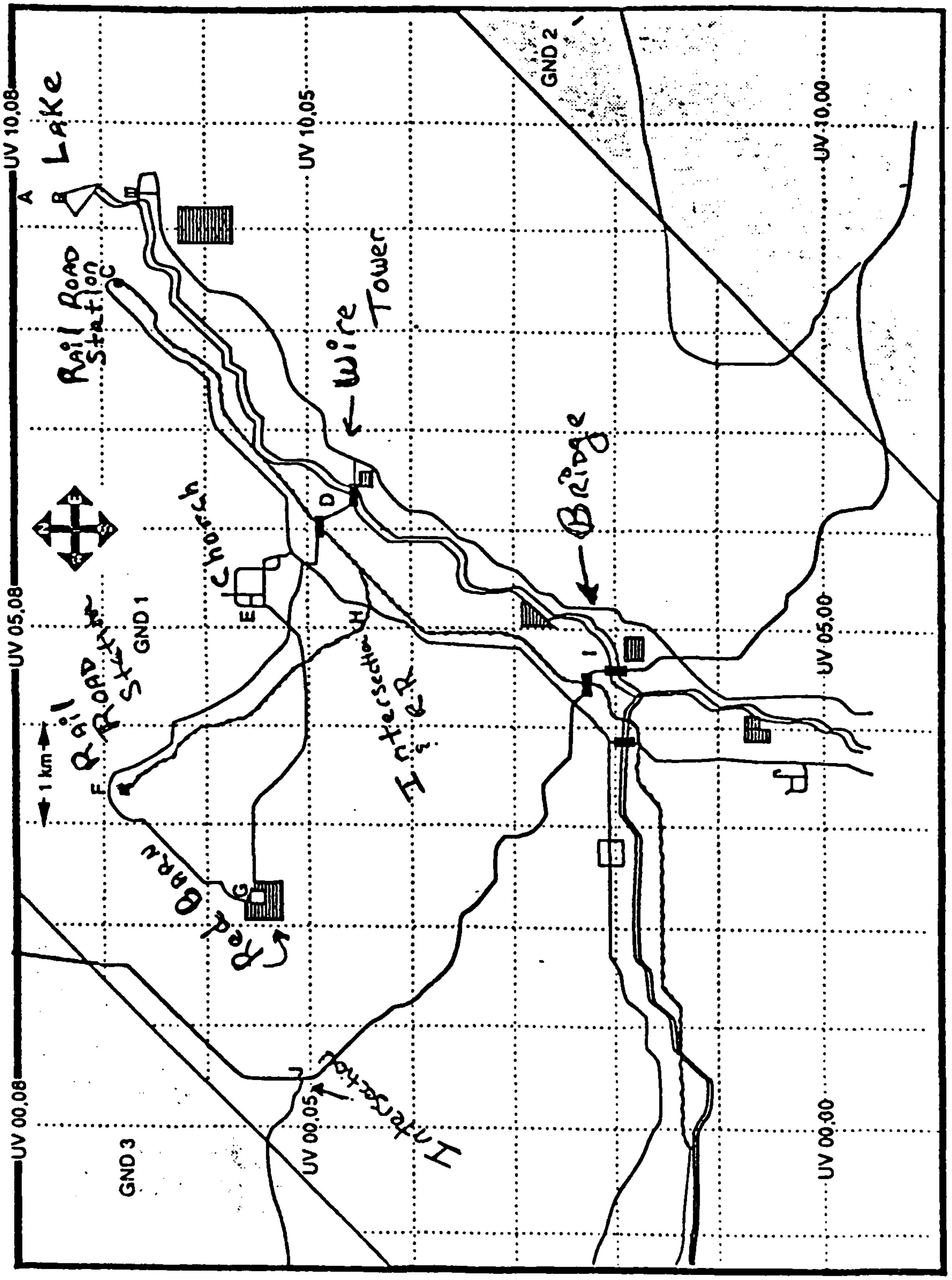
UNIT	C/SIGN	FREQ
ARTY 1/321	S 27	85.60
ATTK A/229	W 30	145.60
ALO 54k TAC	SNOOPY	278.60
JAAT 10k AFW	TOMAHAWK	34.00
FAC A/221	R 3	137.20
GROUND1 1/327	L 6 N	76.35
GROUND2 2/327	L 2 V	81.40
GROUND3 2/211	X 3 R	55.10

FUEL

START: ___

STOP: ___

FUEL CHECK: ___



UV 10,08
UV 05,08
UV 00,08
UV 10,05
UV 00,05
UV 10,00
UV 05,00
UV 00,00
GND 1
GND 2
GND 3
1 km
Lake
Rail Road Station
Wire Tower
Bridge
Church
Rail Road Station
Red Barn
Intersection

APPENDIX B

Pre-flight Briefing for Mission B

Tactical Situation. A Squadron from the 17th CAV has been assigned by the Aviation Brigade Command to support an ATKBN which has been placed under the operational control of ground units within the 2nd Brigade. Your Air Cavalry Troop (ACT) from the squadron has been tasked with conducting zone/route reconaissance to the North of and along the East-West borders of the 2nd Brigade.

Mission Description. The mission given to your ACT is to perform a zone reconnaissance of the assigned area, with the goal of establishing a predetermined Screen Line, which has been depicted on your mission map. To accomplish this mission, your ACT has been divided into Scout Weapons Teams (SWT's), each of which consists of two LHX aircraft.

The area which has been assigned to your two-man SWT has been divided into two separate sectors, the Western sector which you will cover, and the Eastern sector which will be covered by the other member or your SWT, your wingman. As you complete your mission, your wingman will be operating at distance beyond your visual range, and reporting independently to complete his segment of the mission. However, the efforts of you and your wingman will be coordinated through mission planning and timing control of mission milestones (waypoint arrivals and departures, and phaseline crossings). You have been designated as the SWT leader, and as such should expect to be the recipient of orders from you Squadron TOC which are directed to the entire SWT.

While performing your zone reconnaissance, your instructions are to report all threat sightings to the BN S2, utilizing the available communications and reporting capabilities of your LHX aircraft. Since the roadway and bridge system in this region is considered vital to future efforts of the 2nd Brigade, maintain a flight path which allows you to assess the condition of the roads and bridges in your sector. Any obstructions of passageways (roads and bridges) should also be reported immediately to the BN S2, so that this information can be used during tactical planning for this region. The condition of all passable roads and bridges does not need to be reported.

In addition to reporting threat contact to the BN S2, the appropriate ground unit(s) operating in your sector should be notified of all threat sightings and information relevant to their respective areas. Since the ground units of the 2nd Brigade possess only voice communications capability, these reports must be verbal. (Note: The ground units in your sector will not be visible to you, although their boundries will be depicted on your map.) Furthermore, you are to alert your wingman as to any threat sightings which may impact the completion of his segment of the mission.

Once you have reported a threat vehicle or group of threat vehicles to the BN S2 and the appropriate ground unit, that target group may be treated as nonlethal for the duration of the mission. In other words, once they have reported the presence of a threat in the vicinity of a waypoint/checkpoint should not stop you from reaching that waypoint or completing you mission. However, a

flight path which minimizes your exposure to these threats should still be selected.

To aid in the completion of your mission, a series of checkpoints/waypoints has been established in each of the sectors for which your SWT is responsible. You are to establish your own appropriate flightpath by these waypoints which will allow you to complete your mission. All checkpoint/phaseline crossing times should be adhered to as closely as possible, and arrivals at all designated waypoints should be reported to the Squadron TOC. Your wingman will report his checkpoint/phaseline crossings independently.

Intelligence. The security of this region is uncertain. Aggressor armored units have been observed advancing towards this area from the South, but have not yet been committed to battle and have not been observed to have assembled into a massed, unified force. As a result, sightings of small isolated units and groups of threat vehicles are possible. The Aggressor units in this region are equipped primarily with BMP's, T-72 tanks, and ZSU-23-4's. Threat sightings are expected to the South of Phaseline BLACK (your screen line), but are also possible within the boundaries of your sector.

Air-to-Air engagements during the previous 24 hours have essentially neutralized Aggressor tactical air power, although they still retain the ability to interfere with our helicopter activities. Although sightings of Aggressor helicopters (HIND/HAVOC) are not expected, they remain a possibility for which you should be prepared.

Weather. Scattered boken clouds with visibility to 50,000 feet. Wind conditions are calm.

Rules of Engagement. The mission assigned to your Squadron is to support the 2nd Brigade by conducting zone reconnaissance. Your mission is to search for, detect, and immediately report on the strength and location of threat elements while adhering to your predetermined waypoints/checkpoints. You have been cleared into this area to observe and report only, and are cleared to engage only if you have been fired upon and engagement is absolutely necessary for self defense. **NOTE** Once a threat has been reported, it may be treated as non-lethal and should not disrupt your progress to any of the waypoints. However, a flight path which minimizes your exposure to these threats should be selected.

Operations - Mission B

Location	Grid	Physical Landmark	Time
Mission Start Checkpoint A	UU 1208	Mission Start	
Checkpoint B	UU 1209	Bldg in Town	
Checkpoint C	UU 1309	Red Barn	
Checkpoint D	UU 1411	Wire Tower	
Checkpoint E	UU 1312	Wire Tower	
Checkpoint F	UU 1214	Red Barn	
Checkpoint G	UU 1215	Wire Tower (Screen Line)	NLT MT= 0:18:00
Checkpoint H	UU 1315	Intersection of Rivers	
Checkpoint I	UV 1513	Wire Tower	

You will begin your mission from a low hover at Checkpoint A, having recently departed FARP01, where you were refueled with 875 lbs of fuel. FARP01 is scheduled to be in the process of relocation by the completion of your mission, forcing you to return to FARP02, which is located a considerable distance further from Phaseline BLACK. The exact location of FARP02 has yet to be determined.

The flight from your region of Phaseline BLACK to FARP02 will require 300 lbs of fuel. To comply with existing fuel safety margins, you are instructed to report to your SQDN TOC immediately when your fuel level has reached 600 lbs so that you may receive instructions for returning to FARP02 and the coordinates of its exact position.

COMMUNICATIONS

SCOUT/PRI FM 46.45 VHF 124.20 UHF 235.50

SCOUT/ALT 30.30

SQDN E 2 Z SCOUT Y 3

RECON	62	1. W 31	1. B	Brief/Debrief	
CO	01	2. W 32	2. I	Blues insert	
TOC	04	3. Y 7	3. G	Miss. Release	
JTOC	60	4. Y 18	4. D	Rations	
XO	46	5. Y 19	5. W	Water	
P/LDR	51	6.	6. L	LP/OP	
P/SGT	55	7.	7. M	Chg/Mission	
FARP	77			F	FM
				V	VHF
				U	UHF

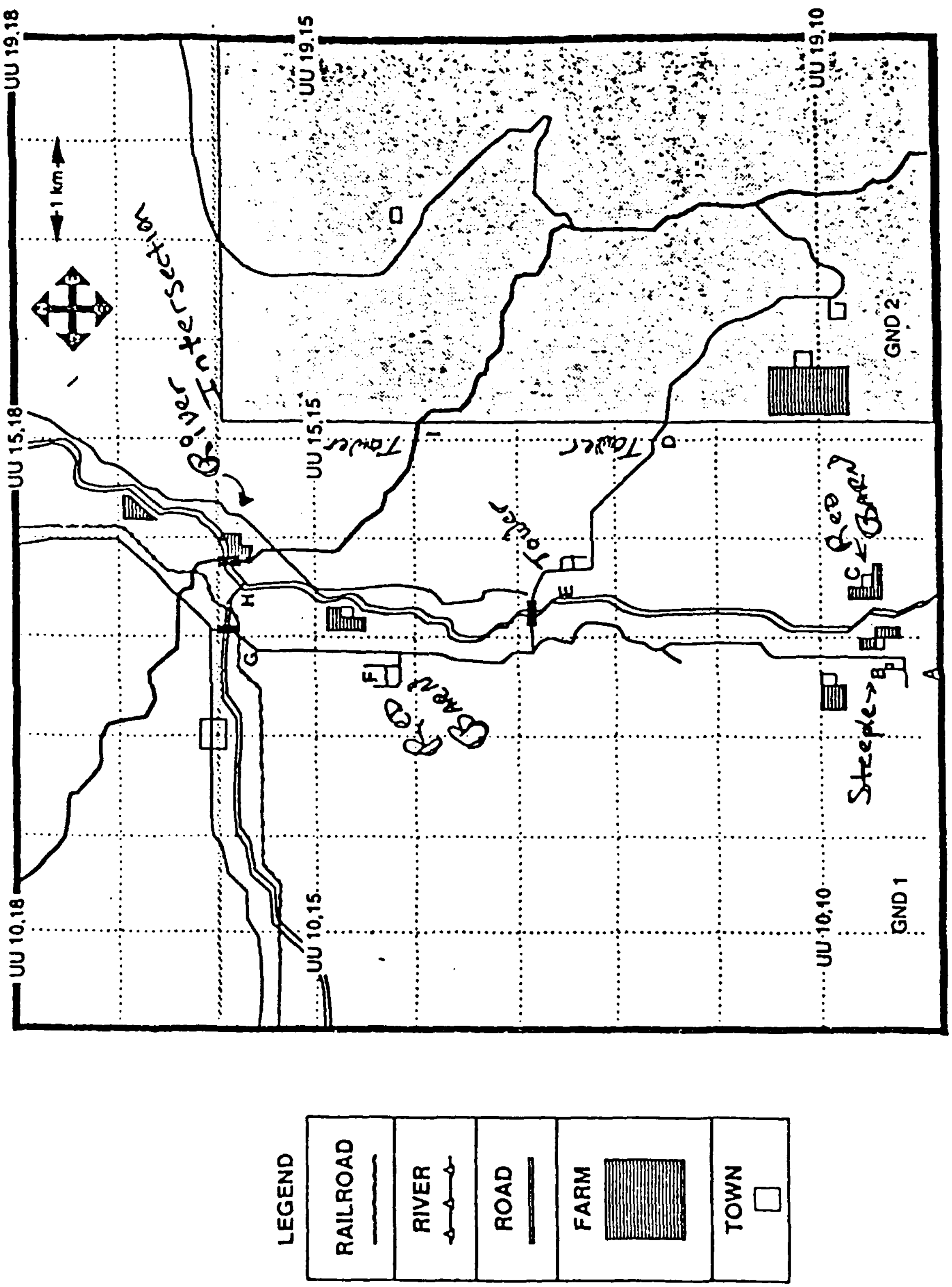
UNIT	C/SIGN	FREQ
ARTY 1/321	S 27	85.60
ATTK A/229	W 30	145.60
ALO 54k TAC	SNOOPY	278.60
JAAT 10k AFW	TOMAHAWK	34.00
FAC A/221	R 3	137.20
GROUND1 1/327	L 6 N	76.35
GROUND2 2/327	L 2 V	81.40
GROUND3 2/211	X 3 R	55.10

FUEL

START: ____lbs

STOP: ____lbs

FUEL CHECK: ____lbs


UU 19.18
UU 19.15
UU 19.10
UU 15.18
UU 15.15
UU 10.18
UU 10.15
UU 10.10
1 km
GND 1
GND 2
A
B
C
D
E
F
G
H
I
River Intersection
Tower
Tower
Tower
Red Barn
Red Barn
Steeple
LEGEND
RAILROAD
RIVER
ROAD
FARM
TOWN

APPENDIX C

Videotape Analysis Scoring Sheets for each Mission and Pilot

PILOT 2 - MISSION A - (0-2671/44:31)

1	60	EM(:07)	HM(:02)02	TM(:09)	Q01	R01	TR01
2	120	EM(:03)	HM(:02)02	TM(:05)	Q01	R01	TR01
		MVSITREP	TSWPB	MV	MV		
3	180	EM(:02)	HM(:00)	TM(:02)			
4	240	EM(:08)	HM(:00)	TM(:08)	TSWPC		
5	300	EM(:00)	HM(:00)	TM(:00)	MVSITREP		
6	360	EM(:02)	HM(:00)	TM(:02)			
7	420	EM(:015)	HM(:01)01	TM(:16)	FCMD	FC	
8	480	EM(:09)	HM(:00)	TM(:09)	Q02	R02	TR02
		TSWPD					
9	540	EM(:04)	HM(:03)02	TM(:07)	MV	MV	
10	600	EM(:02)	HM(:04)02	TM(:06)	Q01	R01	TR01
		MVWPE					
11	660	EM(:03)	HM(:00)	TM(:03)			
12	720	EM(:04)	HM(:03)02	TM(:07)	Q03	R03	TR03
13	780	EM(:09)	HM(:00)	TM(:09)	TSWPF		
14	840	EM(:02)	HM(:05)01	TM(:07)	MVWPF		
15	900	EM(:16)	HM(:00)	TM(:16)	MVSPTRPT	FCMDSPTRPT	
16	960	EM(:04)	HM(:00)	TM(:04)	FC	MVSPTRPT	MVSITREP
17	1020	EM(:04)	HM(:01)01	TM(:09)	Q01	R01	TR01
		MVWPG	MVSITREP				
18	1080	EM(:04)	HM(:06)04	TM(:10)	Q02	R02	TR02
19	1140	EM(:06)	HM(:07)02	TM(:13)	Q01	R01	TR01
20	1200	EM(:11)	HM(:11)05	TM(:22)	Q03	R03	TR03
		FCMDFREQCH		MVAUTH			

21	1260	EM(:05)	HM(:00)	TM(:05)	Q02	R02	TR02
		FC					
22	1320	EM(:09)	HM(:00)	TM(:09)	MV		
23	1380	EM(:05)	HM(:00)	TM(:05)	TSWPH	RB	
24	1440	EM(:09)	HM(:11)06	TM(:20)	Q02	R02	TR02
		MVWPH					
25	1500	EM(:11)	HM(:00)	TM(:11)	Q01	R01	TR01
		FCMD					
26	1560	EM(:11)	HM(:01)01	TM(:12)	FC	MVSITREP	
27	1620	EM(:05)	HM(:00)	TM(:05)	MVSITREP	FCMDSPTRPT	
28	1680	EM(:20)	HM(:00)	TM(:20)			
29	1740	EM(:19)	HM(:01)01	TM(:20)	MDSPTRPT	FC	
30	1800	EM(:14)	HM(:00)	TM(:14)	Q03	R03	TR03
		MVFUELRPT					
31	1860	EM(:09)	HM(:01)01	TM(:10)	Q01	R01	TR01
		MVBDA					
32	1920	EM(:09)	HM(:00)	TM(:09)	Q02	R02	TR02
		MVWPI					
33	1980	EM(:04)	HM(:02)02	TM(:09)			
34	2040	EM(:05)	HM(:01)01	TM(:06)	Q02	R02	TR02
		MV					
35	2100	EM(:04)	HM(:06)05	TM(:10)	Q02	R02	TR02
36	2160	EM(:10)	HM(:00)	TM(:10)	Q01	R01	TR01
		MVSPTRPT	FCMDSPTRPT				
37	2220	EM(:21)	HM(:00)	TM(:21)	Q01	R01	TR01
		MDSPTRPT	FC				
38	2280	EM(:03)	HM(:00)	TM(:03)	Q02	R02	TR02

39	2340	EM(:10)	HM(:00)	TM(:10)	Q02	R02	TR02
40	2400	EM(:04)	HM(:00)	TM(:04)			
41	2460	EM(:10) MVWPJ	HM(:00)	TM(:10)	Q03	R03	TR03
42	2520	EM(:08) TR02	HM(:00)	TM(:08)	Q03	R02	NR01
43	2580	EM(:04)	HM(:00)	TM(:04)	RB		
44	2640	EM(:03) MVSPTRPT	HM(:00)	TM(:03)	Q03	R03	TR03
	2671	EM(:03)	EOM				

PILOT 2 - MISSION B - (0-3005/50:05)

1	60	EM(:07)	HM(:00)	TM(:07)	MV		
2	120	EM(:05)	HM(:01)01	TM(:06)	Q02	R02	TR02
3	180	EM(:09)	HM(:01)01	TM(:10)	Q01	R01	TR01
		MVSITREP					
4	240	EM(:06)	HM(:00)	TM(:06)	TSWPB	MVSITREP	
5	300	EM(:03)	HM(:00)	TM(:03)			
6	360	EM(:11)	HM(:00)	TM(:11)	Q01	R01	TR01
		R8	MVWPC	MVSITREP			
7	420	EM(:11)	HM(:00)	TM(:11)	NAVSYSPROB		MVWPC
8	480	EM(:05)	HM(:00)	TM(:05)			
9	540	EM(:03)	HM(:00)	TM(:03)	POSNADJ		
10	600	EM(:02)	HM(:00)	TM(:02)	Q01	R01	TR01
		MV	MV				
11	660	EM(:13)	HM(:01)01	TM(:14)	HM1	MVSPTRPT	FCMDSPTRPT
		MDSPTRPT					
12	720	EM(:09)	HM(:00)	TM(:09)	FC		
13	780	EM(:04)	HM(:00)	TM(:04)	Q02	R02	TR02
		MVWPD	MVSPTRPT				
14	840	EM(:02)	HM(:00)	TM(:02)	Q01	R01	TR01
		MV	MV				
15	900	EM(:16)	HM(:01)01	TM(:17)	FCMDSPTRPT		
16	960	EM(:23)	HM(:00)	TM(:23)	FC		
17	1020	EM(:02)	HM(:02)02	TM(:04)	Q02	R02	TR02
		HM2	FC				
18	1080	EM(:11)	HM(:04)03	TM(:15)	Q01	R01	TR01
		MDSPTRPT	TSWPE	FC			

19	1140	EM(:05)	HM(:01)01	TM(:06)	Q03	R03	TR03
		MVWPE	FCFREQCH				
20	1200	EM(:16)	HM(:00)	TM(:16)	Q01	R01	TR01
		COMMOPROB	MV				
21	1260	EM(:09)	HM(:10)03	TM(:19)	Q01	R01	TR01
		COMMOPROB					
22	1320	EM(:01)	HM(:15)09	TM(:16)	Q02	R02	TR02
		MVFREQCH	MVAUTH				
23	1380	EM(:03)	HM(:02)02	TM(:05)	Q03	R03	TR03
		MVAUTH	FC	MVSPTRPT			
24	1440	EM(:02)	HM(:00)	TM(:02)	Q01	R01	TR01
		MVSITREP					
25	1500	EM(:18)	HM(:00)	TM(:18)	FCMDSPTRPT		MVSPTRPT
26	1560	EM(:04)	HM(:00)	TM(:04)	MDSPTRPT		
27	1620	EM(:01)	HM(:02)02	TM(:03)	Q02	R02	TR02
		LOST					
28	1680	EM(:03)	HM(:03)03	TM(:06)	Q02	R02	TR02
29	1740	EM(:09)	HM(:00)	TM(:09	Q01	R01	TR01
		MVWPF					
30	1800	EM(:05)	HM(:00)	TM(:05)			
31	1860	EM(:01)	HM(:00)	TM(:01)	MVSPTRPT	POSNADJ	
32	1920	EM(:05)	HM(:00)	TM(:05)	Q03	R03	TR03
		MVFUELRPT					
33	1980	EM(:09)	HM(:00)	TM(:09)	FCFREQCH	MVSPTRPT	MVFUELRPT
		FC					
34	2040	EM(:18)	HM(:00)	TM(:18)	Q01	R01	TR01
		FCMDSPTRPT					
35	2100	EM(:03)	HM(:00)	TM(:03)			

36	2160	EM(:17)	HM(:00)	TM(:17)	MDSPTRPT	FC	
37	2220	EM(:10)	HM(:02)02	TM(:12)			
38	2280	EM(:10)	HM(:00)	TM(:10)	Q02	R02	TR02
		TSWPG	MVSITREP				
39	2340	EM(:03)	HM(:07)05	TM(:10)			
40	2400	EM(:07)	HM(:02)02	TM(:09)	MVSPTRPT	FCMDSPTRPT	
41	2460	EM(:17)	HM(:00)	TM(:17)	Q01	R01	TR01
		MDSPTRPT					
42	2520	EM(:13)	HM(:01)01	TM(:14)	Q01	R01	TR01
43	2580	EM(:07)	HM(:00)	TM(:07)	MVWPH		
44	2640	EM(:02)	HM(:00)	TM(:02)			
45	2700	EM(:02)	HM(:10)08	TM(:12)	Q03	R03	TR03
		MSNCH	MVFUELRPT				
46	2760	EM(:05)	HM(:00)	TM(:05)	Q02	R02	TR02
47	2820	EM(:03)	HM(:01)01	TM(:04)	Q01	R01	TR01
48	2880	EM(:05)	HM(:01)01	TM(:06)			
49	2940	EM(:11)	HM(:06)04	TM(:17)	FCFREQCH	MVAUTH	
50	3000	EM(:03)	HM(:13)09	TM(:16)	Q04	R04	TR04
	3005	EM(:02)	END OF MISSION				

PILOT 3 - MISSION A - (0-2414/40:14)

1	60	EM(:09) MVWPA	HM(:03)03	TM(:12)	Q01	R01	TR01
2	120	EM(:09) TSWPB	HM(:04)03	TM(:13)	Q01	R01	TR01
3	180	EM(:11)	HM(:00)	TM(:11)	MVWPC		
4	240	EM(:07) RB	HM(:02)01	TM(:09)	Q02	R02	TR02
5	300	EM(:04) MVWPD	HM(:05)04 TSMV	TM(:09)	Q01	NR01	TR00
6	360	EM(:05)	HM(:07)04	TM(:12)	MV		
7	420	EM(:07)	HM(:06)03	TM(:13)			
8	480	EM(:06)	HM(:03)02	TM(:09)	TSWPE		
9	540	EM(:08) MVWPF	HM(:02)02	TM(:10)	Q04	R04	TR04
10	600	EM(:06)	HM(:03)03	TM(:09)	Q01	R01	TR01
11	660	EM(:33)	HM(:00)	TM(:33)	FCMDSPTRPT		
12	720	EM(:09) MVSPTRPT	HM(:04)02	TM(:13)	Q01	R01	TR01
13	780	EM(:14) MVWPG	HM(:01)01	TM(:15)	Q02	R02	TR02
14	840	EM(:04) GCXT	HM(:06)04	TM(10)	Q03	R03	TR03
15	900	EM(:10)	HM(:03)02	TM(:13)	Q01	R01	TR01
16	960	EM(:13) FCFREQCH	HM(:04)02 GCXT	TM(:17)	Q02	R02	TR02
17	1020	EM(:20) TR02	HM(:17)02 FREQCH	TM(:37) FREQCH	Q02	R01	LR01

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18   1080  EM(:08) HM(:06)02 TM(:14)     Q03        R02        LR01
            TR03       FC     MVFREQCH

19   1140  EM(:02) HM(:02)01 TM(:04)     Q02        R02        TR02
           MVAUTH

20   1200  EM(:18) HM(:10)02 TM(:28) FCMDSPTRPT              MDSPTRPT

21   1260  EM(:14) HM(:10)05 TM(:24) MDSPTRPT     MD         FC
          MVSPTRPT

22   1320  EM(:02  HM(:05)02 TM(:07)     Q01        R01        TR01
          MVSPTRPT

23   1380  EM(:08) HM(:06)02 TM(:14)     Q01        R01        TR01
            TSWPI

24   1440  EM(:13) HM(:03)01 TM(:16)     Q03        R03        TR03
          FCMDFREQCH            GCXT

25   1500  EM(:07) HM(:01)01 TM(:08) MVFREQCH   GCXT

26   1560  EM(:06)   HM(:00)   TM(:06)   Q02        R02        TR02
             RB        GCXT    TSSPTRPT

27   1620  EM(:11) HM(:07)01 TM(:18) FCMDSPTRPT

28   1680  EM(:04) HM(:20)04 TM(:24) MDSPTRPT MVSPTRPT

29   1740  EM(:03) HM(:05)05 TM(:08)     Q01        R01        TR01
             FC        LOST

30   1800  EM(:08) HM(:07)03 TM(:15)    LOST

31   1860  EM(:05) HM(:03)03 TM(:08)     Q02        R02        TR02
            GCXT

32   1920  EM(:04) HM(:06)06 TM(:10)     Q01        R01        TR01

33   1980  EM(:04)   HM(:00)   TM(:04)   Q01        R02        TR01
          FCMDSPTRPT

34   2040  EM(:24)   HM(:00)   TM(:24)

35   2100  EM(:09) HM(:01)01 TM(:10)     Q01        R01        TR01
            GCXT       FC     TSFUELRPT
```

36	2160	EM(:05)	HM(:02)01	TM(:07)	Q02	R02	TR02
		TSWPJ					
37	2220	EM(:17)	HM(:01)01	TM(:18)	Q01	R01	TR01
		MVWPJ(LATE)					
38	2280	EM(:07)	HM(01)01	TM(:08)			
39	2340	EM(:11)	HM(:00)	TM(:11)	Q01	R01	TR01
40	2400	EM(:14)	HM(:00)	TM(:14)	Q01	R01	TR01
	2414	EM(:01)	HM(:00)	TM(:01)	Q01	R01	TR01
		EOM					

PILOT 3 - MISSION B - (0-1835/30:35)

1 60 EM(:07) HM(:06)02 TM(:13) MVWPB

2 120 EM(:04) HM(:04)02 TM(:08) TSWPC

3 180 EM(:07) HM(:05)05 TM(:12) FC

4 240 EM(:01) HM(:08)06 TM(:09) Q01 R01 TR01
MVWPD

5 300 EM(:04) HM(:07)04 TM(:11) Q01 R01 TR01
RB TSWPE

6 360 EM(:11) HM(:10)02 TM(:21) MVSPTRPT FCMDSPTRPT
TSMV

7 420 EM(:18) HM(:00) TM(:18) Q01 R01 TR01
FC MVSPTRPT

8 480 EM(:01) HM(:04)02 TM(:05)

9 540 EM(:02) HM(:14)04 TM(:16) MVSPTRPT

10 600 EM(:15) HM(:02)02 TM(:17) FCMDSPTRPT FC

11 660 EM(:08) HM(:03)03 TM(:11) Q01 R01 TR01
MVWPF

12 720 EM(:22) HM(:10)03 TM(:32) MVSPTRPT FCMDSPTRPT
FCFREQCH TSMV

13 780 EM(:01) HM(:08)03 TM(:09) Q04 R04 TR04
MVAUTH FC

14 840 EM(:12) HM(:03)01 TM(:15) Q02 R02 TR02
TSWPG MVWPG

15 900 EM(:11) HM(:02)01 TM(:13) Q03 R02 NR01
TR02 FCFREQCH FC

16 960 EM(:30) HM(:04)02 TM(:34) FCMDSPTRPT MVSPTRPT

17 1020 EM(:13) HM(:05)05 TM(:18) Q03 R03 TR03
TSWPH

18	1080	EM(:07)	HM(:00)	TM(:07)	Q01	R01	TR01
19	1140	EM(:08)	HM(:04)03	TM(:12)	Q03	R03	TR03
			MSNCH				
20	1200	EM(:08)	HM(:05)02	TM(:13)	Q02	R02	TR02
		FCFREQCH	TSWPI				
21	1260	EM(:04)	HM(:11)05	TM(:15)	Q03	R03	TR03
		MVAUTH					
22	1320	EM(:06)	HM(:01)01	TM(:07)	Q02	R02	TR02
23	1380	EM(:08)	HM(:00)	TM(:08)	Q03	R03	TR03
24	1440	EM(:03)	HM(:11)03	TM(:14)	Q01	R01	TR01
		MVFUELRPTMVSPTRPT					
25	1500	EM(:10)	HM(:00)	TM(:10)	FCMDSPTRPT		
26	1560	EM(:06)	HM(:04)02	TM(:10)	Q02	R02	TR02
		MVWPJ	MV				
27	1620	EM(:06)	HM(:00)	TM(:06)	Q02	R02	TR02
		MSNCH					
28	1680	EM(:08)	HM(:00)	TM(:08)	Q01	R01	TR01
29	1740	EM(:08)	HM(:00)	TM(:08)	Q01	R01	TR01
		RB					
30	1800	EM(:13)	HM(:00)	TM(:13)	RB		
	1835	EM(:02)	HM(:00)	TM(:02)	MVWPK	EOM	

PILOT 4 - MISSION A - (0-2245/37:25)

1	60	EM(:08)	HM(:00)	TM(:08)	Q04	R04	TR04	
		FC	TSWPB					
2	120	EM(:02)	HM(:14)05	TM(:16)	Q03	R03	TR03	
		MVWPB(LATE)		FCMDSPTRPT				
3	180	EM(:00)	HM(:03)03	TM(:03)	Q01	R01	TR01	
		TSWPC						
4	240	EM(:00)	HM(:00)	TM(:00)				
5	300	EM(:03)	HM(:00)	TM(:03)				
6	360	EM(:05)	HM(:12)02	TM(:17)	FCMDSPTRPT			
7	420	EM(:04)	HM(:02)01	TM(:06)	Q03	R03	TR03	
		MVSPTRPT						
8	480	EM(:06)	HM(:01)01	TM(:07)				
9	540	EM(:03)	HM(:00)	TM(:03)	Q02	R01	LR01	
		TR02	TSSPTRPT	MV				
10	600	EM(:00)	HM(:05)02	TM(:05)	TSWPE			
11	660	EM(:00)	HM(:01)01	TM(:01)	GCXT			
12	720	EM(:02)	HM(:00)	TM(:02)	Q04	R04	TR04	
		GCXT	TSWPF					
13	780	EM(:00)	HM(:15)06	TM(:15)	MVWPF	FCMDSPTRPT		
			FC					
14	840	EM(:02)	HM(:01)01	TM(:03)	FCMDSPTRPT			
15	900	EM(:00)	HM(:14)07	TM(:14)	Q01	R01	TR01	
		MD	MVSPTRPT	FC				
16	960	EM(:00)	HM(:01)01	TM(:01)	Q02	R02	TR02	
		POSNADJ	MVAUTH					
17	1020	EM(:00)	HM(:02)01	TM(:02)	TSWPG			

```
18    1080  EM(:01) HM(:02)02 TM(:03)    Q02      R02      TR02
             POSNADJ    MSNCH

19    1140  EM(:00) HM(:11)07 TM(:11)    Q03      R03      TR03
            FCFREQCH   MVAUTH

20    1200  EM(:04) HM(:01)01 TM(:05)    FC

21    1260  EM(:00)  HM(:00)  TM(:00)   TSWPH

22    1320  EM(:02) HM(:20)07 TM(:22) FCMDSPTRPT

23    1380  EM(:03) HM(:02)02 TM(:05) MVSPTRPT   GCXT

24    1440  EM(:02) HM(:02)01 TM(:04)    Q03      R03      TR03
            COMMOPROB

25    1500  EM(:01) HM(:11)04 TM(:12)    Q02      R02      NR01
              TR02    MVSPTRPT FCMDSPTRPT

26    1560  EM(:01) HM(:22)06 TM(:23)    Q02      R02      TR03
            FCMDFREQCH

27    1620  EM(:03) HM(:07)02 TM(:10)    Q01      R01      TR01
            MVFUELRPT   TSWPI

28    1680  EM(:00) HM(:04)02 TM(:04)   FCMD     GCXT

29    1740  EM(:01) HM(:29)07 TM(:30) MDSPTRPT

30    1800  EM(:01)  HM(:00)  TM(:01)    Q01      R01      TR01

31    1860  EM(:02) HM(:01)01 TM(:03) FCMDSPTRPT          MVSPTRPT
               FC        TSMV

32    1920  EM(:03) HM(:11)02 TM(:14)    FC

33    1980  EM(:02) HM(:03)03 TM(:05)    Q02      R02      TR02
               FC

34    2040  EM(:01) HM(:05)04 TM(:06)    Q02      R02      TR02
              MVWPJ
35    2100  EM(:01) HM(:02)02 TM(:03)    Q01      R01      TR01
```

36	2160	EM(:00)	HM(:00)	TM(:00)			
37	2220	EM(:02)	HM(:01)01	TM(:03)	TSWPK	FCMDSPTRPT	
	2245	EM(:00)	HM(:06)03	TM(:06)	Q01	R01	TR01
		EOM					

PILOT 4 - MISSION B - (0-2232/37:12)

1	60	EM(:07)	HM(:01)01	TM(:08)	Q01	R01	TR01
2	120	EM(:06)	HM(:06)01	TM(:08)	TSWPB	MVWPB	
3	180	EM(:09)	HM(:00)	TM(:09)	Q01	R01	TR01
4	240	EM(:09)	HM(:06)03	TM(:15)	TSWPC		
5	300	EM(:09)	HM(:00)	TM(:09)	Q02	R02	TR02
		GCXT					
6	360	EM(:06)	HM(:00)	TM(:06)	TSWPD		
7	420	EM(:06)	HM(:17)04	TM(:24)	Q02	R02	TR02
		FCMDSPTRPT		FC	MVWPD		
8	480	EM(:06)	HM(:00)	TM(:06)			
9	540	EM(:04)	HM(:05)03	TM(:09)	TSWPE		
10	600	EM(:02)	HM(:05)03	TM(:07)	Q04	R04	TR04
		TSSPTRPT					
11	660	EM(:15)	HM(:00)	TM(:15)	Q03	R03	TR03
		TS					
12	720	EM(:01)	HM(:02)02	TM(:03)	Q02	R02	TR02
		TSWPF					
13	780	EM(:03)	HM(:18)05	TM(:21)	FCMDSPTRPT		
14	840	EM(:03)	HM(:01)01	TM(:04)	Q02	R02	TR02
		MVSPTRPT					
15	900	EM(:08)	HM(:22)05	TM(:30)	Q01	R01	TR01
		FCFREQCH	MV				
16	960	EM(:04)	HM(:06)04	TM(:10)	Q04	R04	TR04
		MVAUTH	MV	FC			
17	1020	EM(:04)	HM(:06)04	TM(:10)	Q03	R03	TR03
		FCMDSPTRPT		MV			

18	1080	EM(:04)	HM(:11)03	TM(:15)	MDSPTRPT	FC	MVWPG
19	1140	EM(:06)	HM(:00) MV	TM(:06)	Q01	LR01	TR01
20	1200	EM(:12) MDFREQCH	HM(:01)01	TM(:13)	Q04	R04	TR04
21	1260	EM(:01) MVWPH(WRONG)	HM(:22)01	TM(:23) FC	Q01 MVFREQCH	R01	TR01
22	1320	EM(:05)	HM(:00) TSSPTRPT	TM(:05)	Q03	R03	TSR03
23	1380	EM(:07) MSNCH	HM(:06)01	TM(:13)	Q02	R02	TR02
24	1440	EM(:01) MSNCH	HM(:11)06 FCMDSPTRPT	TM(:12)	Q01	R01	TR01
25	1500	EM(:02) MDSPTRPT	HM(:23)05	TM(:24)	Q02	R02	TR02
26	1560	EM(:03) MVWPH	HM(:16)03	TM(:19)	MVSPTRPT	FCMD	
27	1620	EM(:01) MV	HM(:08)05 TSWPJ	TM(:09)	Q01	R01	TR01
28	1680	EM(:06)	HM(:04)02	TM(:10)	Q02	R02	TR02
29	1740	EM(:05) TSSPTRPT	HM(:01)01	TM(:06)	Q02	R02	TR02
30	1800	EM(:08) LOSS OF CONTROL	HM(:00)	TM(:08)	Q03	R03	TR03
31	1860	EM(:06) GCXT	HM(:00) GCXT	TM(:06)	Q02	R02	TR02
32	1920	EM(:01) FCMDSPTRPT	HM(:07)03	TM(:08)	Q01	R01	TR01
33	1980	EM(:05)	HM(:12)05	TM(:17)	MVWPJ(WRONG)		
34	2040	EM(:06)	HM(:00)	TM(:06)	Q02	R02	TR02

35	2100	EM(:07) TSWPJ	HM(:00)	TM(:07)	Q03	R03	TR03
36	2160	EM(:06) FC	HM(:01)01	TM(:07)	Q01	R01	TR01
37	2220	EM(:08)	HM(:01)01	TM(:09)	Q01	R01	TR01
	2232	EOM					

PILOT 5 - MISSION A - (0-2831/47:11)

1	60	EM(:07)	HM(:01)01	TM(:08)	Q01	R01	TR01
		MVWPB(WRONG)		FC			
2	120	EM(:01)	HM(:04)02	TM(:05)	Q03	R03	TR03
		MVWPB(WRONG)					
3	180	EM(:00)	HM(:02)02	TM(:02)	Q02	R02	TR02
		TS					
4	240	EM(:02)	HM(:00)	TM(:02)	Q04	R03	NR01
		TR03	TSWPB				
5	300	EM(:03)	HM(:05)03	TM(:08)			
6	360	EM(:02)	HM(:02)02	TM(:06)	TSWPC		
7	420	EM(:03)	HM(:00)	TM(:03)	Q02	R02	TR02
8	480	EM(:01)	HM(:06)03	TM(:07)	LOST		
9	540	EM(:00)	HM(:18)07	TM(:18)	MVSPTRPT		
10	600	EM(:02)	HM(:00)	TM(:02)	FCMDSPTRPT		TSWPD
11	660	EM(:01)	HM(:07)03	TM(:08)	FC	TSSPTRPT	
		MVWPD(LATE)					
12	720	EM(:01)	HM(:03)02	TM(:04)			
13	780	EM(:03)	HM(:07)05	TM(:10)	Q02	R02	TR02
		MVWPF(WRONG)					
14	840	EM(:01)	HM(:02)02	TM(:03)	Q02	R02	TR02
		TSWPF					
15	900	EM(:00)	HM(:05)04	TM(:05)	Q01	R01	TR01
16	960	EM(:04)	HM(:03)03	TM(:07)	GCXT	MVSPTRPT	GCXT
17	1020	EM(:08)	HM(:10)02	TM(:18)	Q02	R02	TR02
		FCMDSPTRPT		FC			
18	1080	EM(:02)	HM(:09)06	TM(:11)	MVSPTRPT	MVWPG	

19	1140	EM(:02)	HM(:00)	TM(:02)			
20	1200	EM(:00)	HM(:11)02	TM(:11)	Q02	R02	TR02
21	1260	EM(:01)	HM(:09)07	TM(:11)	Q02	R02	TR02
		MSNCH					
22	1320	EM(:00)	HM(:15)06	TM(:15)			
		MVFREQCH	MVFUELRPT				
23	1380	EM(:01)	HM(:30)07	TM(:31)	Q03	R03	TR03
		MVAUTH	MV				
24	1440	EM(:03)	HM(:04)04	TM(:07)	Q01	R01	TR01
		POSNADJ					
25	1500	EM(:02)	HM(:03)03	TM(:05)	Q02	R02	TR02
26	1560	EM(:01)	HM(:02)01	TM(:03)	Q01	R01	TR01
		MVSPTRPT	TSRPT				
27	1620	EM(:00)	HM(:14)07	TM(:17)	MVSPTRPT	FCMDSPTRPT	
28	1680	EM(:15)	HM(:02)01	TM(:17)			
29	1740	EM(:04)	HM(:04)03	TM(:08)	FC	TSWPH	
		TSMDSPTRPT					
30	1800	EM(:04)	HM(:01)01	TM(:05)	Q02	R02	TR02
31	1860	EM(:17)	HM(:01)01	TM(:18)	Q01	R01	TR01
		FCFREQCH	FC				
32	1920	EM(:02)	HM(:01)01	TM(:03)	Q02	R02	TR02
		MVSPTRPT					
33	1980	EM(:02)	HM(:01)01	TM(:03)			
34	2040	EM(:00)	HM(:01)01	TM(:01)			
35	2100	EM(:01)	HM(:08)03	TM(:09)	MVSPTRPT		
36	2160	EM(:09)	HM(:15)04	TM(:24)	FCMDSPTRPT		
37	2220	EM(:03)	HM(:03)02	TM(:06)	MV		

38	2280	EM(:05) MVWPI	HM(:02)02 FC	TM(:07) FC	Q01	R01	TR01
39	2340	EM(:06)	HM(:08)04	TM(:14)	Q01	R01	TR01
40	2400	EM(:02)	HM(:06)03	TM(:08)			
41	2460	EM(:02) MVSPTRPT	HM(:10)02	TM(:12)	Q01	R01	TR01
42	2520	EM(:19) MDSPTRPT	HM(:00)	TM(:19)	Q01	R01	TR01
43	2580	EM(:04)	HM(:00)	TM(:04)	FC		
44	2640	EM(:00)	HM(:02)02	TM(:02)	POSNADJ		
45	2700	EM(:02)	HM(:04)02	TM(:06)	Q02	R02	TR02
46	2760	EM(:04)	HM(:04)04	TM(:08)	Q03	R03	TR03
47	2820	EM(:02)	HM(:03)02	TM(:05)			
	2831	EOM					

PILOT 5 - MISSION B - (0-2920/49:20)

1	60	EM(:05)	HM(:01)01	TM(:06)	Q02	R02	TR02
		MVWPB					
2	120	EM(:02)	HM(:03)03	TM(:05)			
3	180	EM(:00)	HM(:01)01	TM(:01)			
4	240	EM(:04)	HM(:01)01	TM(:05)	Q01	R01	TR01
5	300	EM(:02)	HM(:03)03	TM(:05)			
6	360	EM(:03)	HM(:02)02	TM(:05)	Q01	R01	TR01
		MVWPD	MVSPTRPT				
7	420	EM(:08)	HM(:04)01	TM(:12)	FCMDSPTRPT		MVSPTRPT
8	480	EM(:02)	HM(:07)02	TM(:09)	Q02	R02	TR02
		FC					
9	540	EM(:02)	HM(:02)02	TM(:04)	TSWPE	TSSITREP	
		FCMDSPTRPT					
10	600	EM(:02)	HM(:04)03	TM(:04)	FC		
11	660	EM(:09)	HM(:01)01	TM(:10)	Q02	R02	TR02
		FREQCH					
12	720	EM(:04)	HM(:01)01	TM(:05)	Q03	R03	TR03
13	780	EM(:08)	HM(:11)05	TM(:19)	Q02	R02	TR02
		FCMDFREQCH		MVAUTH			
14	840	EM(:02)	HM(:05)03	TM(:07)	Q02	R02	TR02
15	900	EM(:07)	HM(:06)03	TM(:13)	Q01	R01	TR01
16	960	EM(:07)	HM(:02)02	TM(:09)	Q01	R01	TR01
		MDSPTRPT	FC	TSWPF			
17	1020	EM(:00)	HM(:05)04	TM(:05)	Q01	R01	TR01
			MVWPF(LATE)				
18	1080	EM(:02)	HM(:02)02	TM(:04)	RB		

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19      1140   EM(:00) HM(:03)02 TM(:03)    MVWPG   MVSPTRPT    TSMD
                 RB

20      1200   EM(:03) HM(:07)06 TM(:10)     Q01         R01       TR01
              MVSPTRPT    TSMD        MV

21      1260   EM(:04) HM(:08)03 TM(:12) FCMDSPTRPT

22      1320   EM(:01) HM(:01)01 TM(:02)     Q02         R02       TR02

23      1380   EM(:06) HM(:03)02 TM(:09) MVSPTRPT FCMDSPTRPT

24      1440   EM(:02) HM(:08)03 TM(:10)     Q01         R01       TR01
              FCMDSPTRPT          MVSPTRPT

25      1500   EM(:01) HM(:02)02 TM(:03)     Q02         R02       TR02
                 FC

26      1560   EM(:00) HM(:03)03 TM(:03)     Q03         R03       TR03
              FCMDFREQCH              MV    LOST

27      1620   EM(:00) HM(:04)03 TM(:04)

28      1680   EM(:01) HM(:01)01 TM(:01)    GCXT         FC        TSWPH
              MVFUELRPT

29      1740   EM(:05) HM(:03)03 TM(:08)     Q01         R01       TR01

30      1800   EM(:03) HM(:02)02 TM(:05)     Q02         R02       TR02
                MSNCH

31      1860   EM(:04) HM(:02)02 TM(:06)

32      1920   EM(:00) HM(:07)04 TM(:07)

33      1980   EM(:00) HM(:10)09 TM(:10)

34      2040   EM(:03) HM(:02)02 TM(:05)     Q01         R01       TR01

35      2100   EM(:01) HM(:09)06 TM(:10)     Q01         R01       TR01
              MVSPTRPT

36      2160   EM(:00) HM(:14)03 TM(:14)    TSWPI       TSMV
              FCMDSPTRPT
37      2220   EM(:03) HM(:18)05 TM(:21) MDSPTRPT FCFREQCH      MV
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38     2280  EM(:00)  HM(:00)   TM(:00)    Q03       R03      TR03
             MVAUTH

39     2340  EM(:08) HM(:02)01 TM(:10)    Q03       R02      LR01
              TR03       FC

40     2400  EM(:03) HM(:03)03 TM(:06)    Q01       R01      TR01

41     2460  EM(:06) HM(:02)01 TM(:08)    MV     MVSPTRPT

42     2520  EM(:02) HM(:07)01 TM(:09) MVSPTRPT FCMDSPTRPT

43     2580  EM(:01) HM(:21)01 TM(:22)    Q02       R02      TR02
            MDSPTRPT     FC

44     2640  EM(:03)  HM(:00)   TM(:03)    Q02       R02      TR02

45     2700  EM(:00) HM(:07)03 TM(:07) FCMDSPTRPT         MVSPTRPT
               RB

46     2760  EM(:01) HM(:09)01 TM(:10)    Q01       R01      TR01
            FCMDFREQCH

47     2820  EM(:01) HM(:04)02 TM(:05)    Q01       R01      TR01
            FCFREQCH     FC

48     2880  EM(:01)  HM(:00)   TM(:01)   MVWPJ

       2920  EM(:00)  HM(:00)   TM(:00)   GCXT    ENEMYCONTACT
               EOM
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PILOT 6 - MISSION A - (0-1323/22:03)

1	60	EM(:14)	HM(:01)01	TM(:05)	Q01	R01	TR01
		MVWPB	FC				
2	120	EM(:14)	HM(:06)04	TM(:20)	Q02	R02	TR02
		MVWPC					
3	180	EM(:16)	HM(:02)01	TM(:18)	FCMDSPTRPT		
4	240	EM(:22)	HM(:17)10	TM(:39)	TSWPD	MVSPTRPT	FC
5	300	EM(:15)	HM(:02)02	HM(:13)	FCMDSPTRPT		
6	360	EM(:03)	HM(:01)01	TM(:04)	Q01	R01	TR01
		TSWPE	FC	MVWPD(INCOR)			
7	420	EM(:04)	HM(:00)	TM(:04)	MVWPF		
8	480	EM(:16)	HM(:00)	TM(:16)	Q03	R03	TR03
		TSWPG	FCMDSPTRPT		MVSPTRPT		
9	540	EM(:14)	HM(:05)04	TM(:19)	FC		
10	600	EM(:06)	HM(:01)01	TM(:07)	Q02	R02	TR02
		MVWPD(INCOR)		MVSPTRPT(LATE)			
11	660	EM(:07)	HM(:05)04	TM(:12)	Q02	R02	TR02
		TSWPH	MVAUTH	FC			
12	720	EM(:12)	HM(:01)01	TM(:13)	TSWPI		
13	780	EM(:31)	HM(:04)02	TM(:35)	MVWPG(INCOR)		
		FCMDSPTRPT		FC			
14	840	EM(:01)	HM(:02)01	TM(:03)	Q04	R04	TR04
15	900	EM(:01)	HM(:05)03	TM(:06)	Q03	R03	TR03
		LOST					
16	960	EM(:02)	HM(:02)02	TM(:04)		MVSPTRPT	
17	1020	EM(:18)	HM(:00)	TM(:18)	Q03	R03	TR03
		FCFREQCH					
18	1080	EM(:10)	HM(:00)	TM(:10)	Q02	R02	TR02

19	1140	EM(:14) MVWPJ	HM(:02)02 TSFUELRPT	TM(:16) FC	Q01	R01	TR01
20	1200	EM(:04)	HM(:00)	TM(:04)			
21	1260	EM(:11)	HM(:00)	TM(11)	Q02	R02	TR02
22	1320	EM(:09) MVWPK	HM(:00)	TM(:09)	Q01	R01	TR01
	1323	EOM					

PILOT 6 - MISSION B - (0-1485/24:45)

1 60 EM(:08) HM(:04)02 TM(:12) Q01 R01 TR01
MVWPB

2 120 EM(:04) HM(:03)03 TM(:07) Q01 R01 TR01

3 180 EM(:02) HM(:05)03 TM(:07) TSWPC

4 240 EM(:06) HM(:00) TM(:06

5 300 EM(:17) HM(:00) TM(:17) TSWPD FCMDSPTRPT

6 360 EM(:18) HM(:10)04 TM(:28) MVSPTRPT

7 420 EM(:10) HM(:06)02 TM(:16) MVWPC FC

8 480 EM(:12) HM(:06)04 TM(18) FCMDSPTRPT MVSPTRPT

9 540 EM(:02) HM(:05)05 TM(:07) Q02 R02 TR02

10 600 EM(:11) HM(:05)03 TM(:16) MDSPTRPT TSWPF

11 660 EM(:04) HM(:08)04 TM(:12) Q03 R03 TR03
MVSPTRPT

12 720 EM(:14) HM(:10)05 TM(:24) Q01 R01 TR01
TSWPG FCFREQCH MVAUTH

13 780 EM(:14) HM(:01)01 TM(:15) Q02 R02 TR02
FCMDSPTRPT

14 840 EM(:06) HM(:07)03 TM(:13) Q02 R02 TR02
MVWPF(INCOR) FC TSWPH

15 900 EM(:29) HM(:00) TM(:29) Q02 R02 TR02
FCMDSPTRPT

16 960 EM(:07) HM(:05)03 TM(:12) Q01 R01 TR01
MVSPTRPT FCFREQCH MVWPG(INCOR)

17 1020 EM(:05) HM(:02)02 TM(:07) Q04 R04 TR04

18 1080 EM(:06) HM(:11)09 TM(:17) Q03 R03 TR03
TSWPH

```
19     1140  EM(:05) HM(:11)08 TM(:16)     Q02       R02       TR02
            FCFREQCH  MVAUTH  TSFUELRPT

20     1200  EM(:03) HM(:06)06 TM(:09)     Q02       R02       TR02

21     1260  EM(:04) HM(:04)04 TM(:08)     Q02       R02       TR02
               FC

22     1320  EM(:17) HM(:01)01 TM(:18)     Q03       R03       TR03
            FCMDSPTRPT             TSWPJ  MVSPTRPT

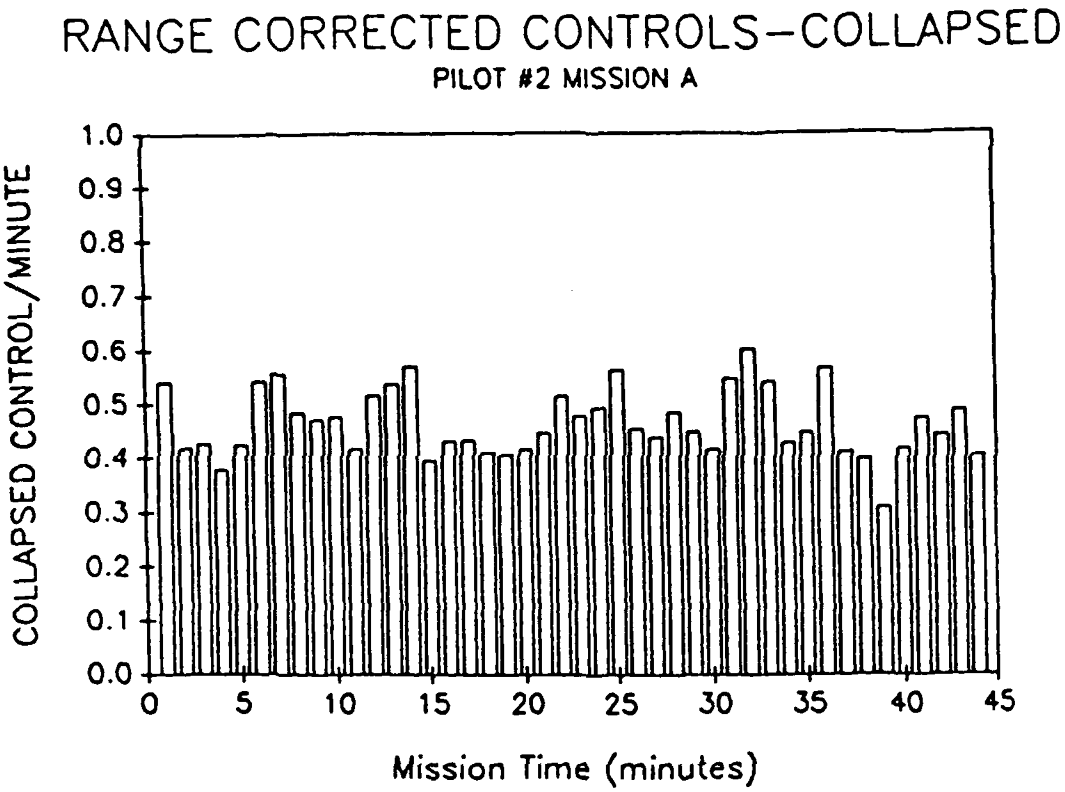
23     1380  EM(:11)  HM(:00)   TM(:11)    Q01       R01       TR01
            MVFUELRPT    FC

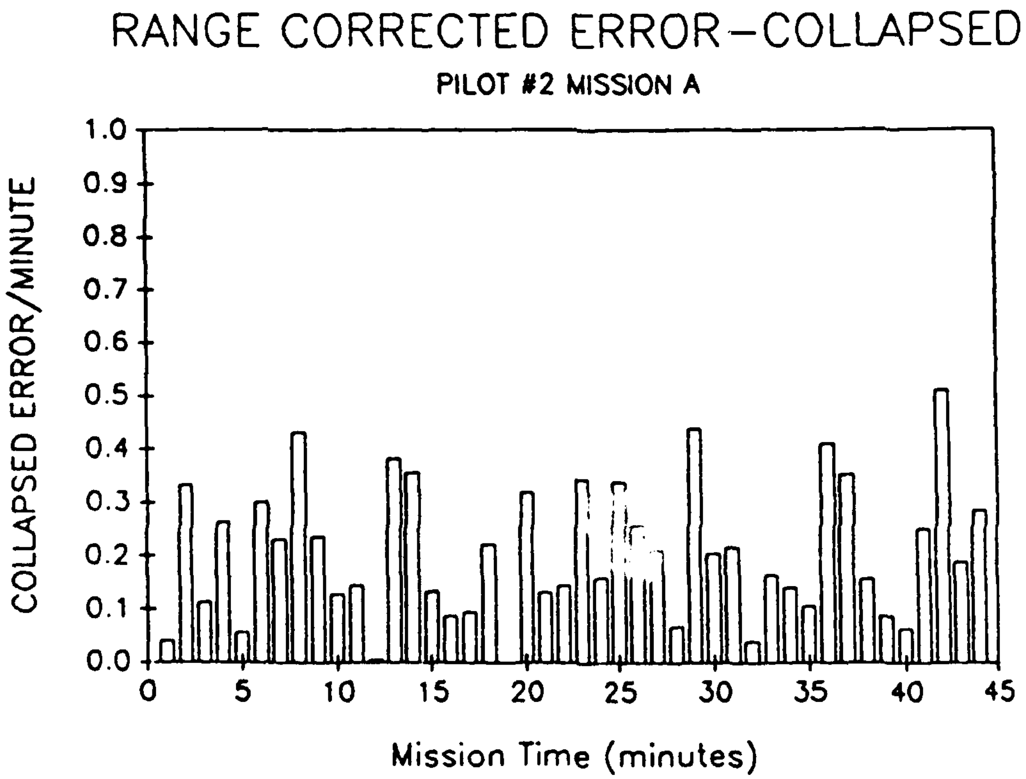
24     1440  EM(:07)  HM(:00)   TM(:07)    Q02       R02       TR02

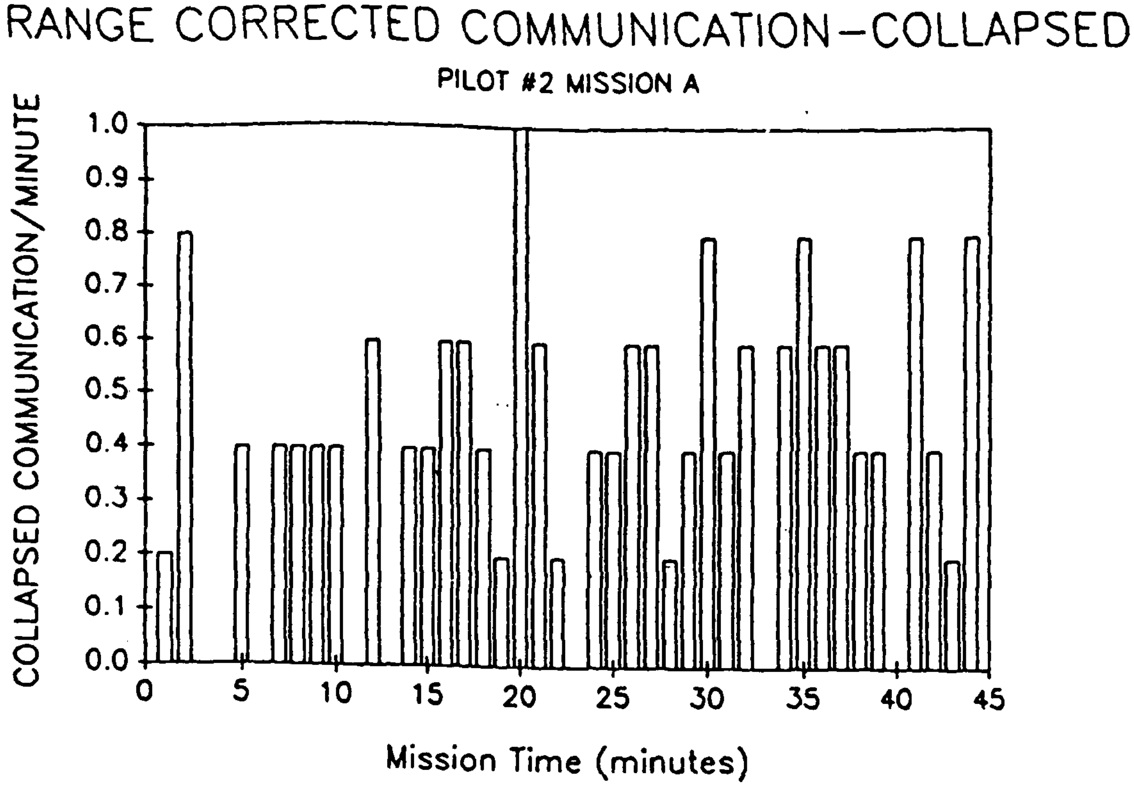
       1485  EM(:06)  HM(:00)   TM(:07)    Q02       R02       TR02
               EOM
```

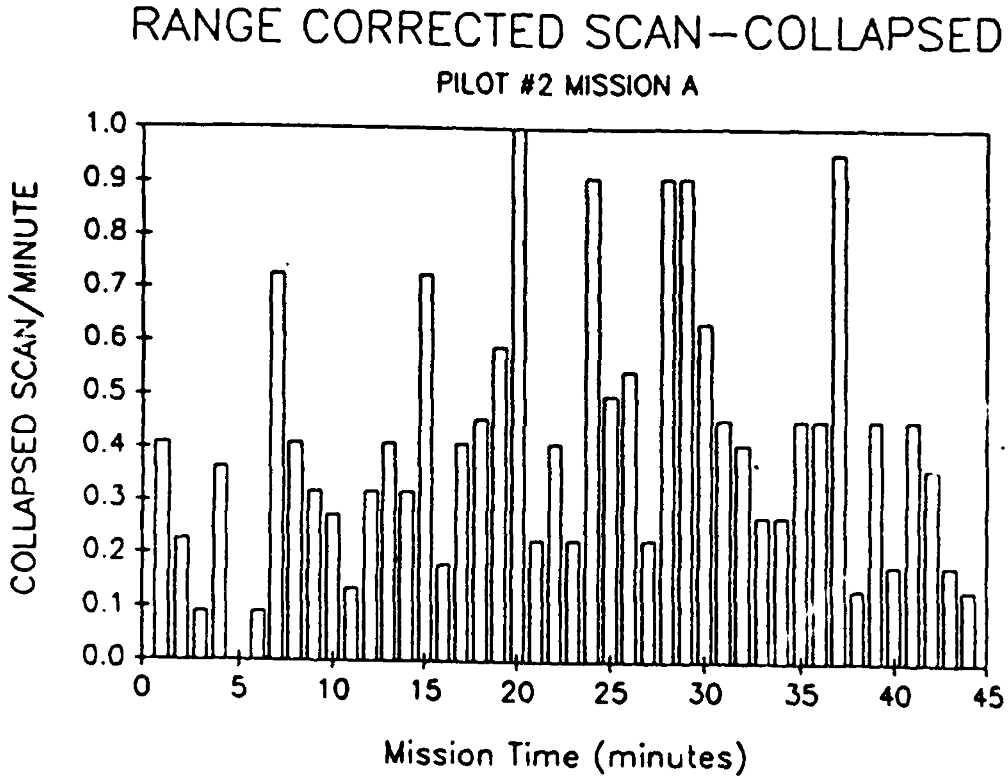
APPENDIX D

Plots of Global Performance Measures for each Pilot and Mission


RANGE CORRECTED CONTROLS–COLLAPSED
PILOT #2 MISSION A
COLLAPSED CONTROL/MINUTE
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
5
10
15
20
25
30
35
40
45
Mission Time (minutes)

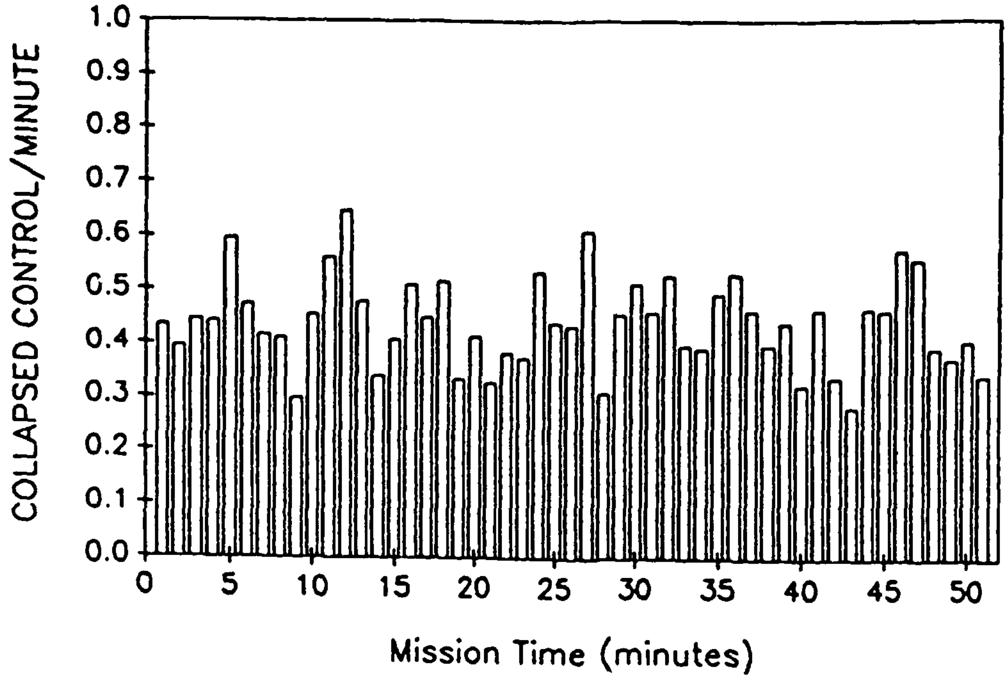

RANGE CORRECTED ERROR–COLLAPSED
PILOT #2 MISSION A
COLLAPSED ERROR/MINUTE
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
5
10
15
20
25
30
35
40
45
Mission Time (minutes)


RANGE CORRECTED COMMUNICATION-COLLAPSED
PILOT #2 MISSION A
COLLAPSED COMMUNICATION/MINUTE
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
5
10
15
20
25
30
35
40
45
Mission Time (minutes)


RANGE CORRECTED SCAN-COLLAPSED
PILOT #2 MISSION A
COLLAPSED SCAN/MINUTE
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
5
10
15
20
25
30
35
40
45
Mission Time (minutes)

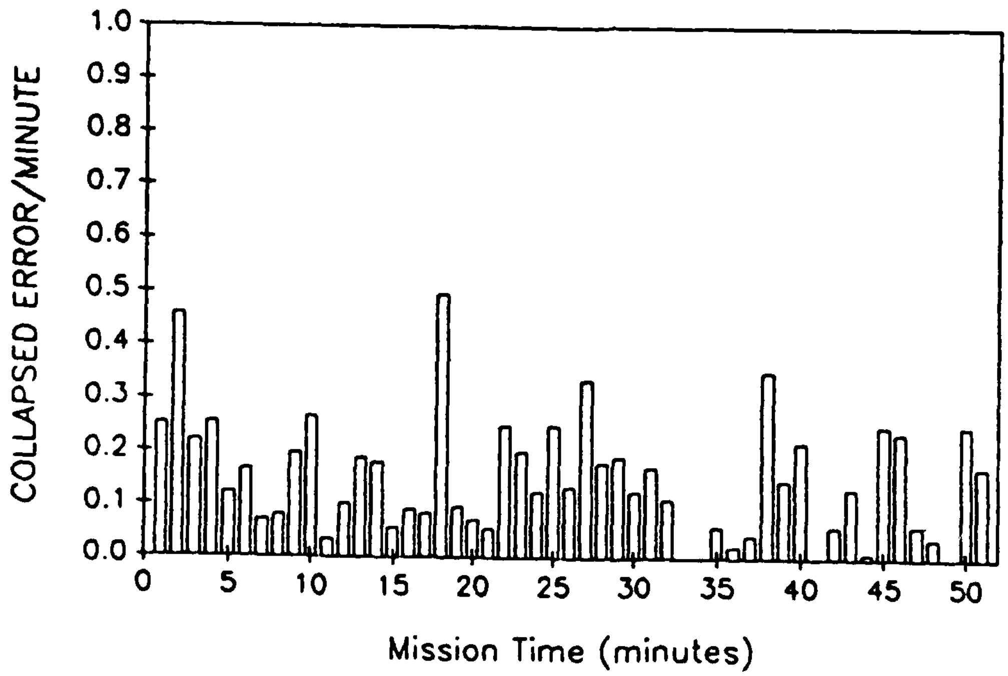
RANGE CORRECTED CONTROLS-COLLAPSED

PILOT 2 MISSION B



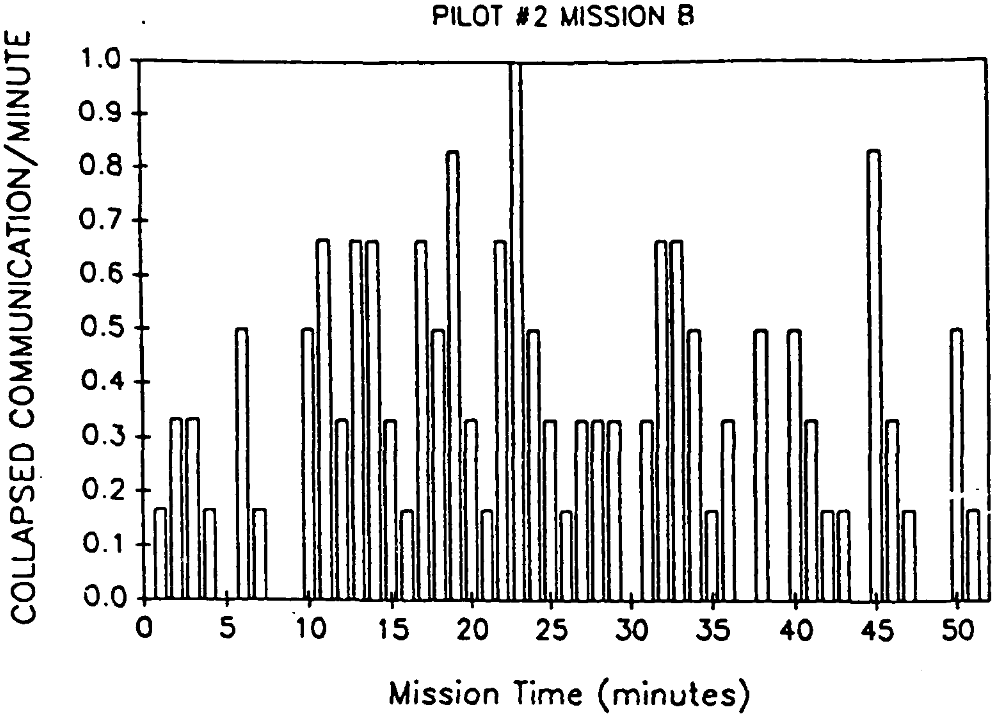
RANGE CORRECTED ERROR-COLLAPSED

PILOT #2 MISSION B



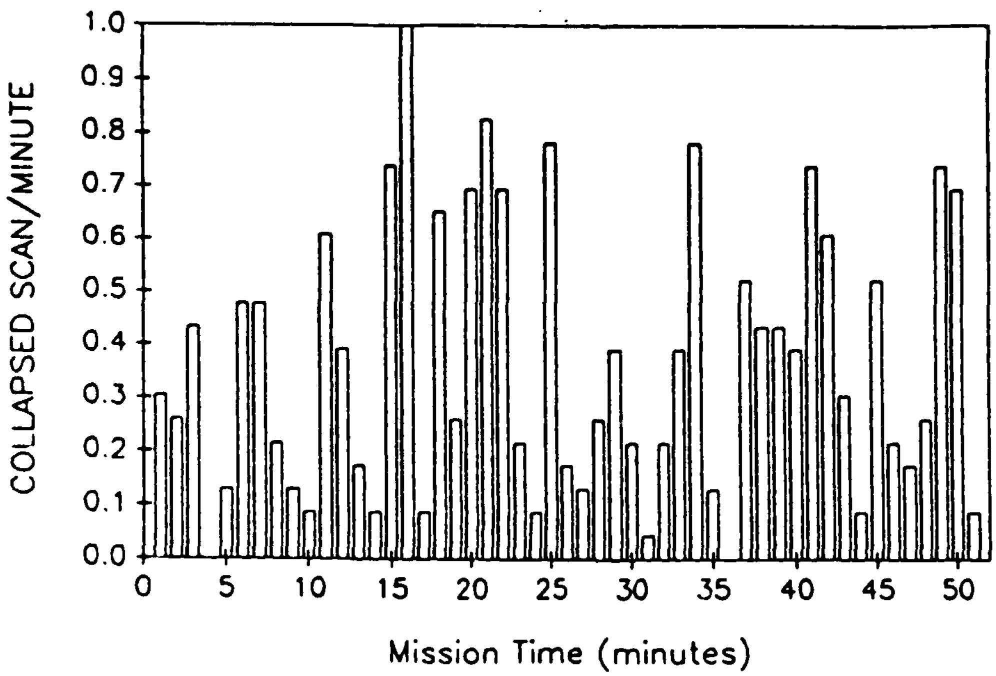
RANGE CORRECTED COMMUNICATION–COLLAPSED

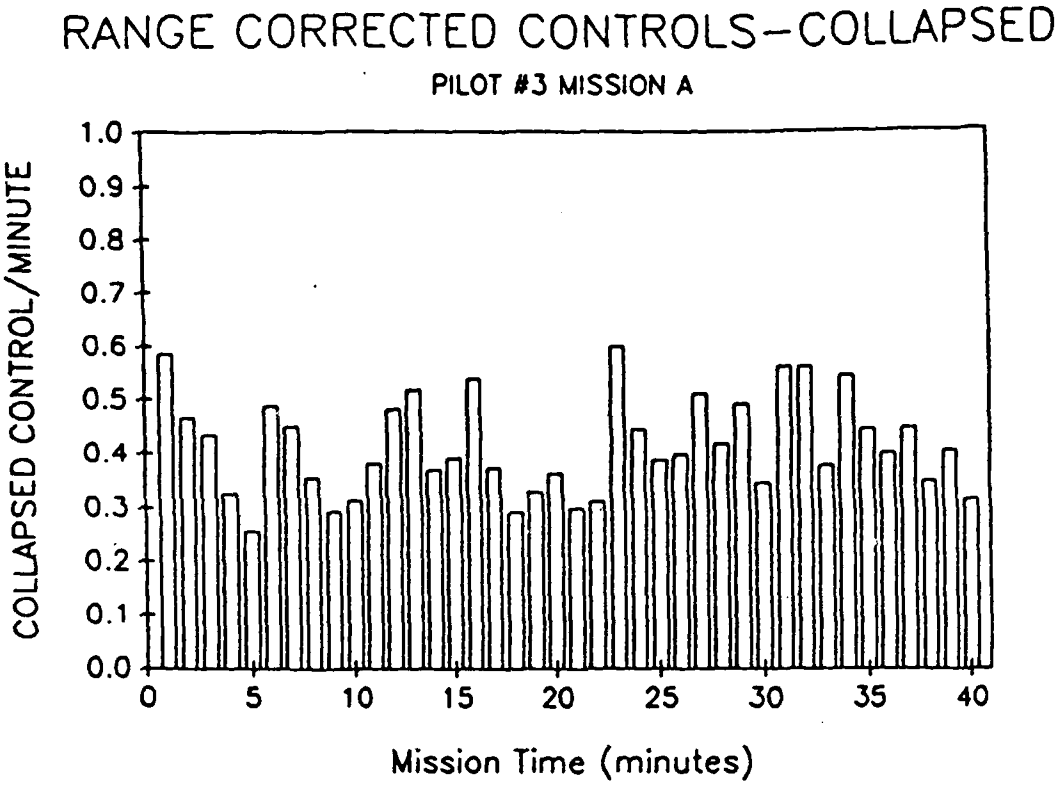
PILOT #2 MISSION B

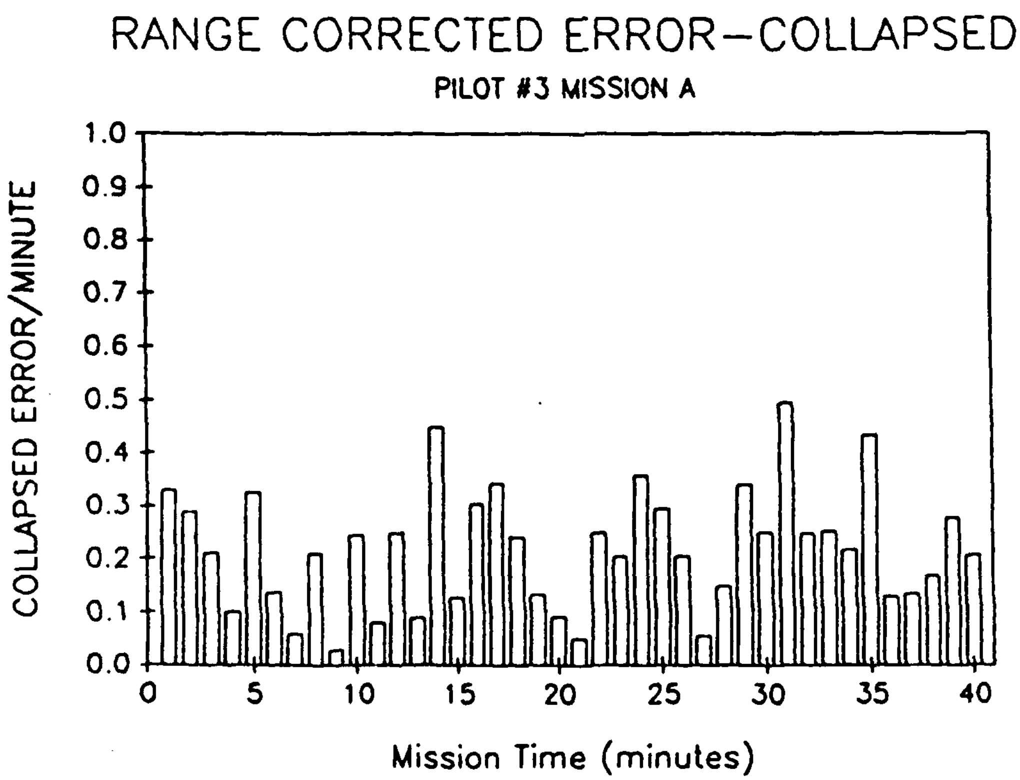


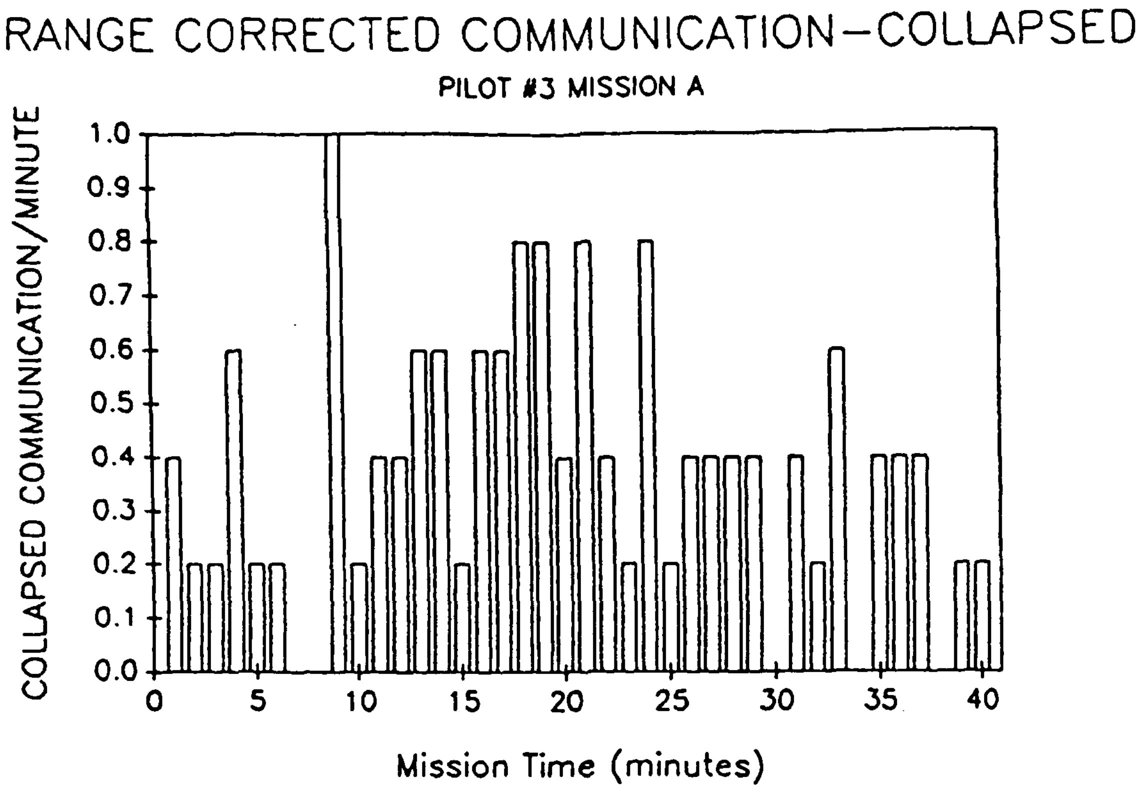
RANGE CORRECTED SCAN–COLLAPSED

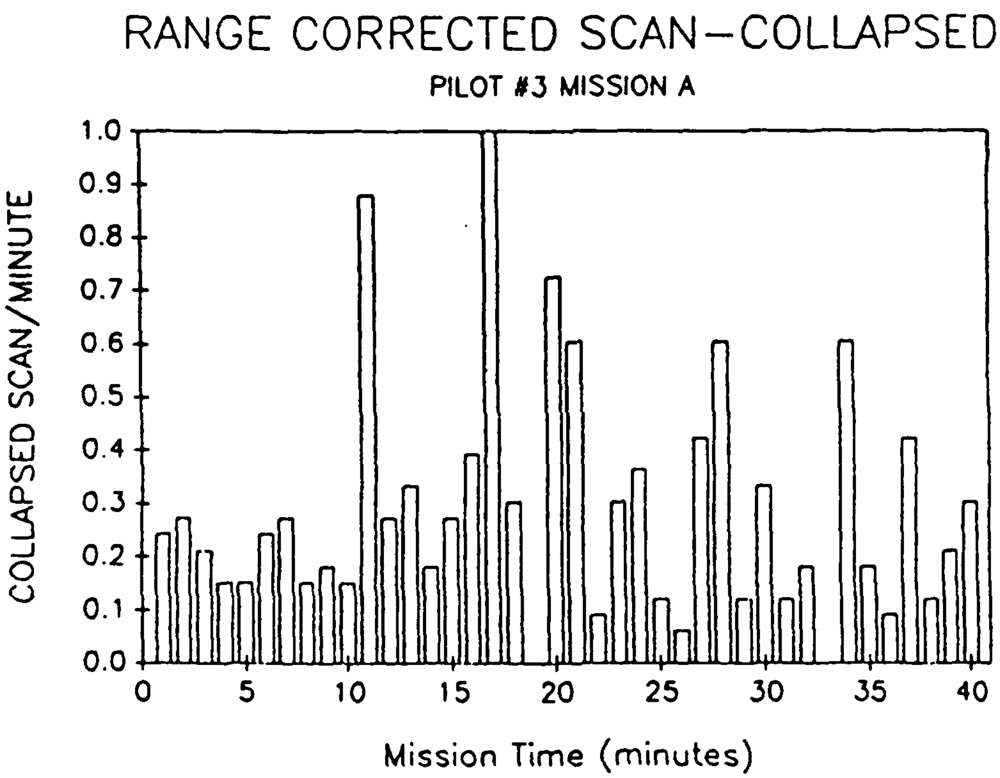
PILOT #2 MISSION B

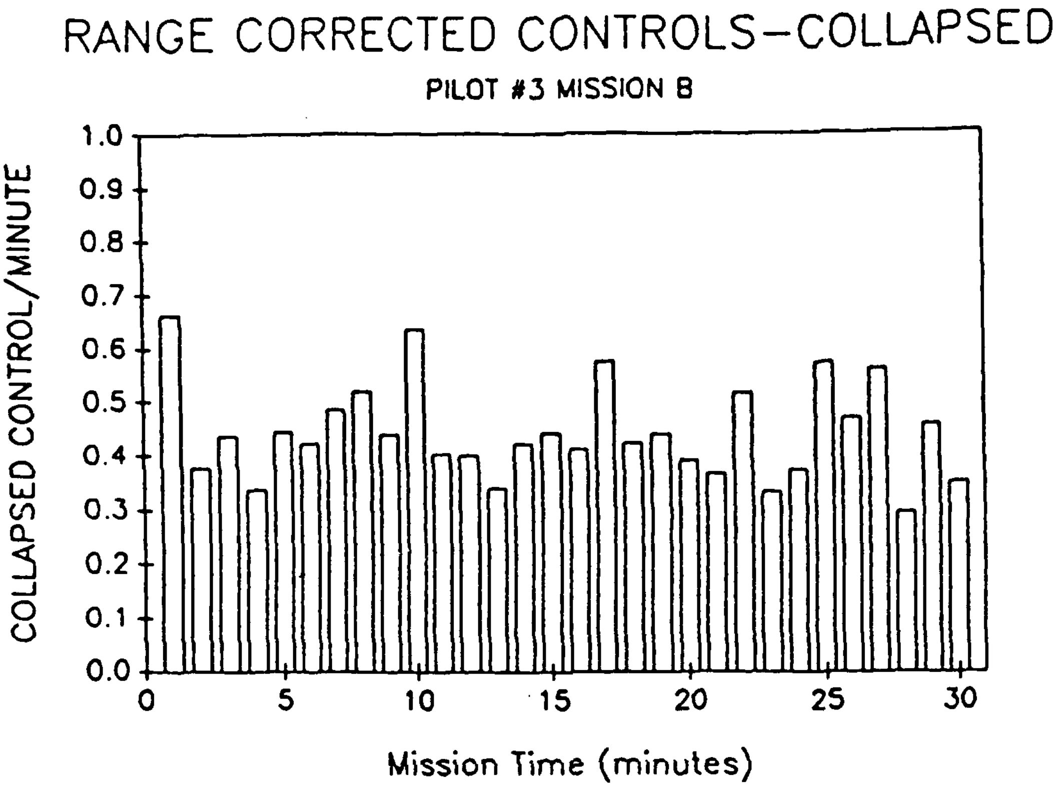


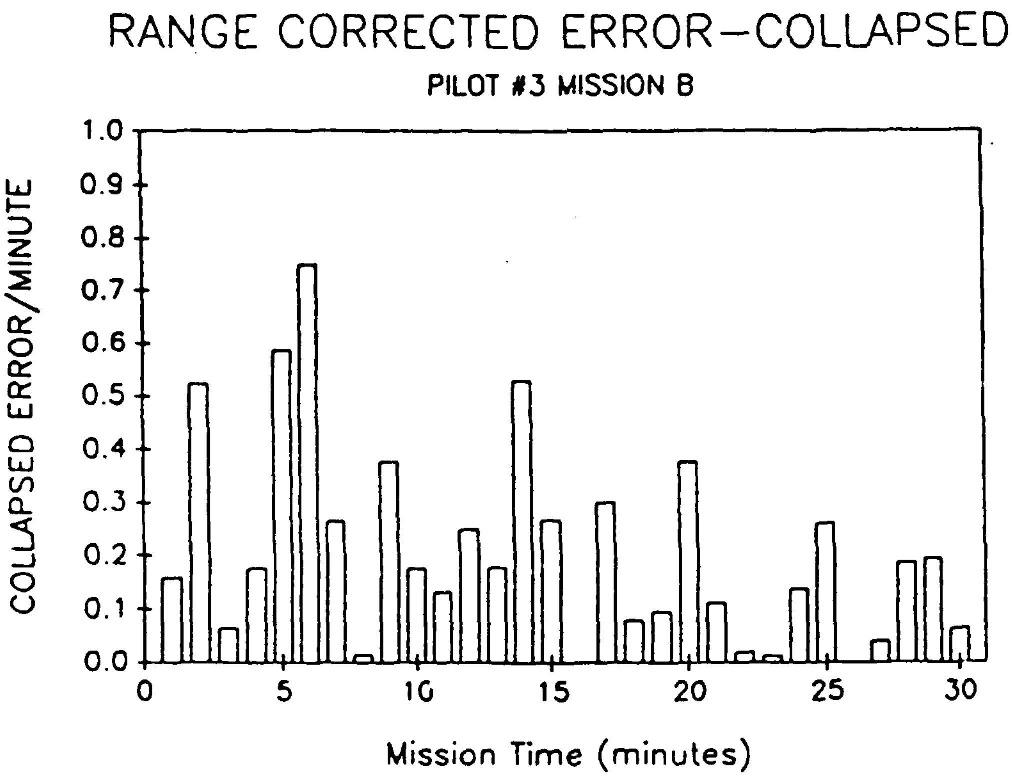

RANGE CORRECTED CONTROLS–COLLAPSED
PILOT #3 MISSION A
COLLAPSED CONTROL/MINUTE
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
5
10
15
20
25
30
35
40
Mission Time (minutes)

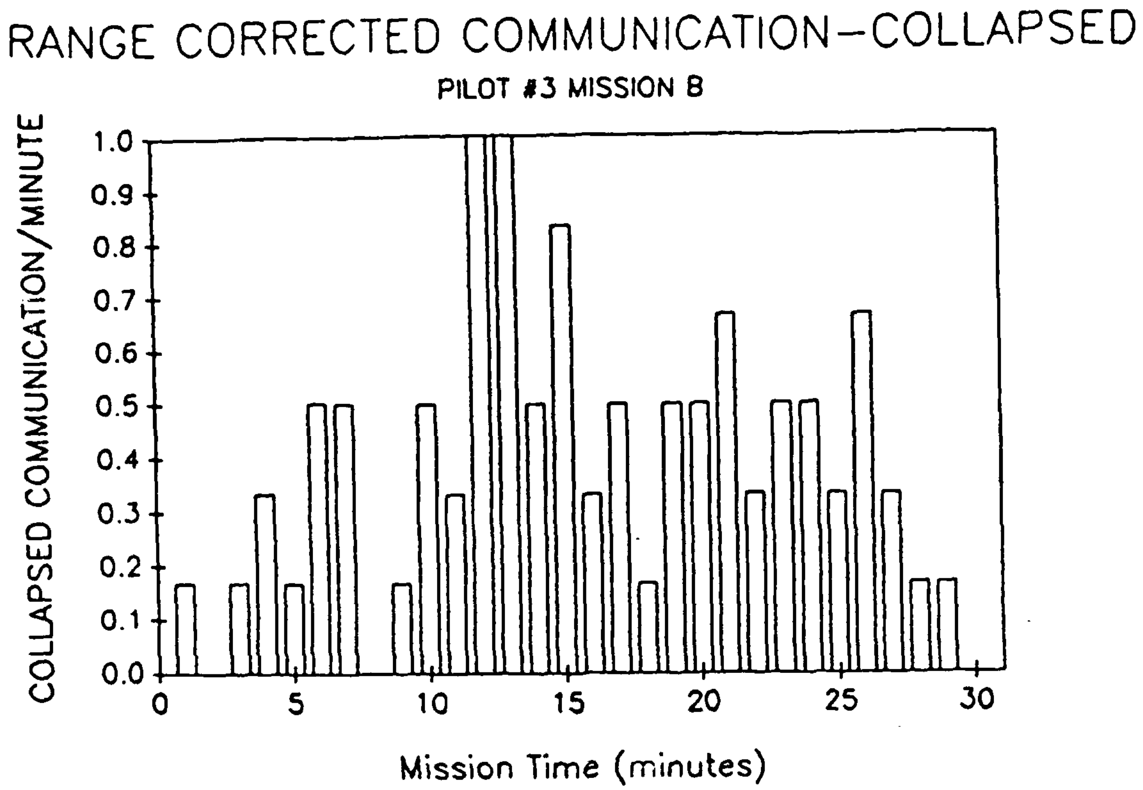

RANGE CORRECTED ERROR–COLLAPSED
PILOT #3 MISSION A
COLLAPSED ERROR/MINUTE
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
5
10
15
20
25
30
35
40
Mission Time (minutes)

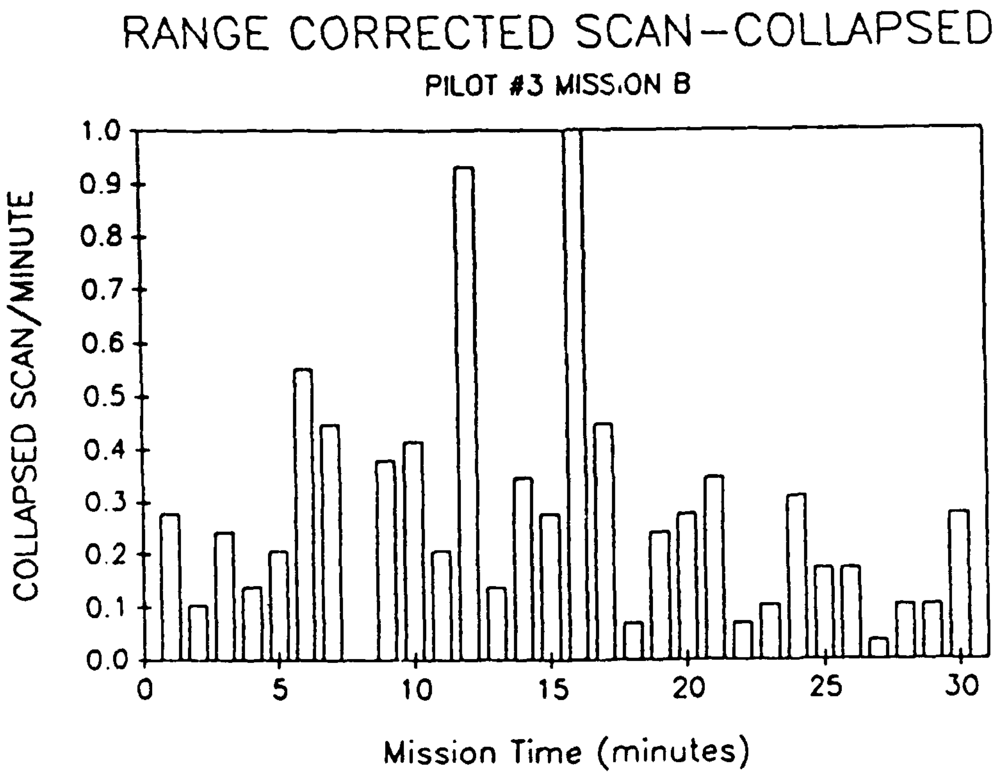

RANGE CORRECTED COMMUNICATION–COLLAPSED
PILOT #3 MISSION A
COLLAPSED COMMUNICATION/MINUTE
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
5
10
15
20
25
30
35
40
Mission Time (minutes)

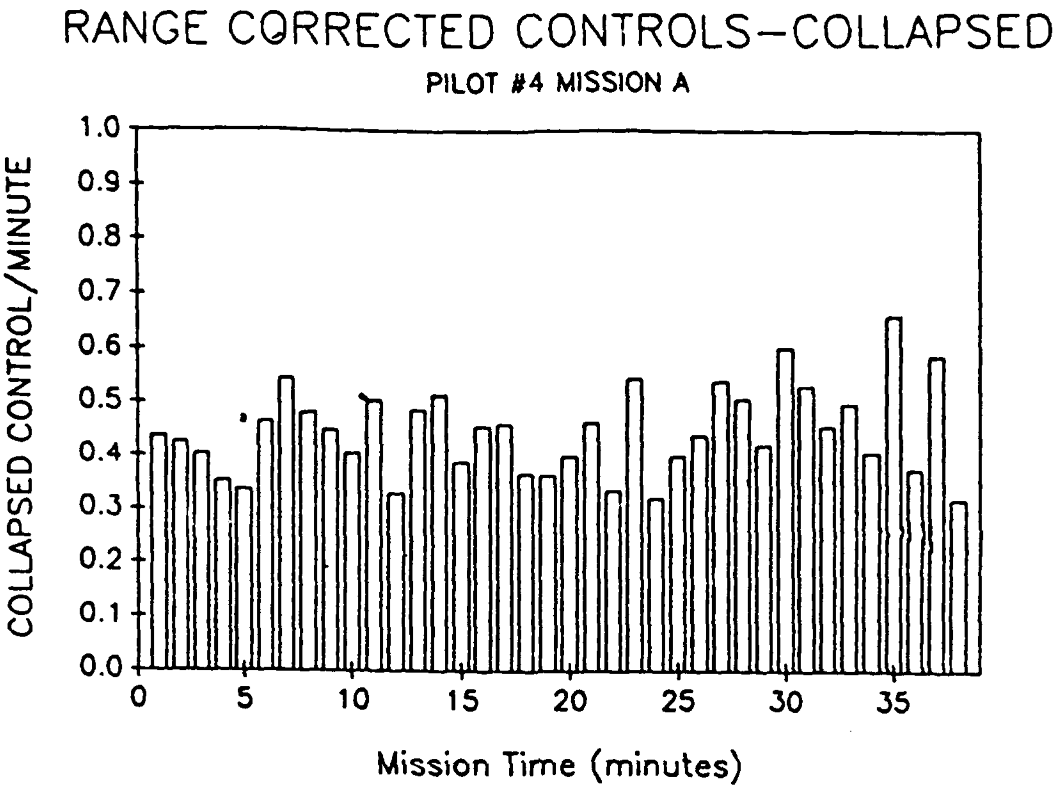

RANGE CORRECTED SCAN–COLLAPSED
PILOT #3 MISSION A
COLLAPSED SCAN/MINUTE
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
5
10
15
20
25
30
35
40
Mission Time (minutes)

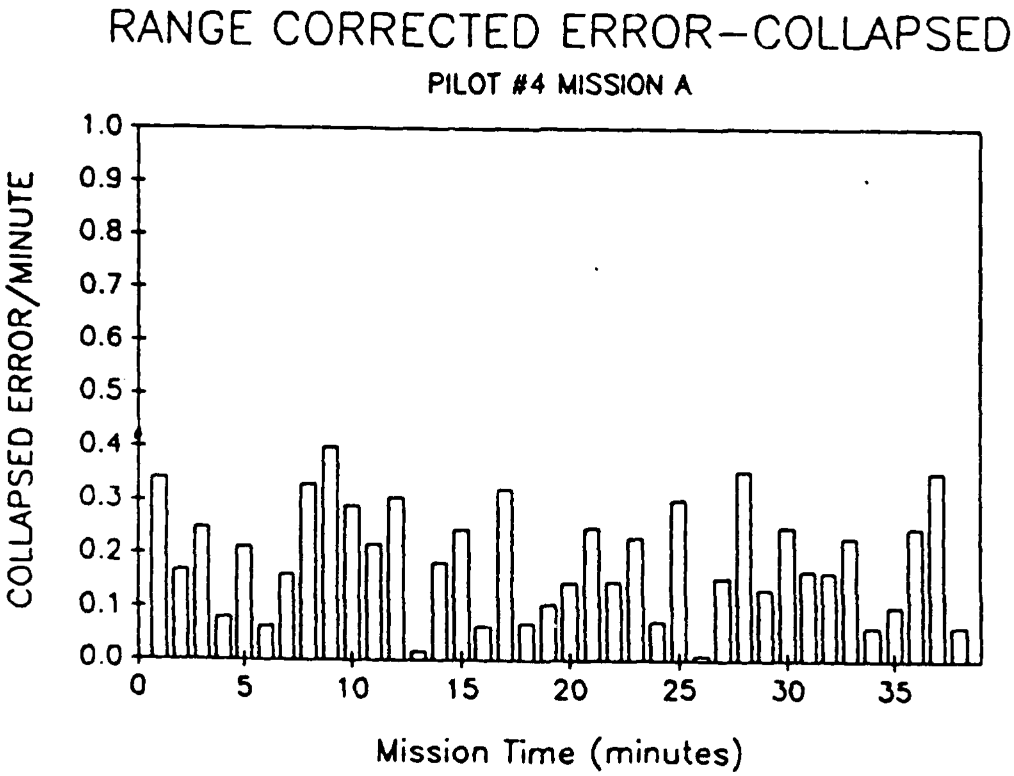

RANGE CORRECTED CONTROLS–COLLAPSED
PILOT #3 MISSION B
COLLAPSED CONTROL/MINUTE
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
5
10
15
20
25
30
Mission Time (minutes)

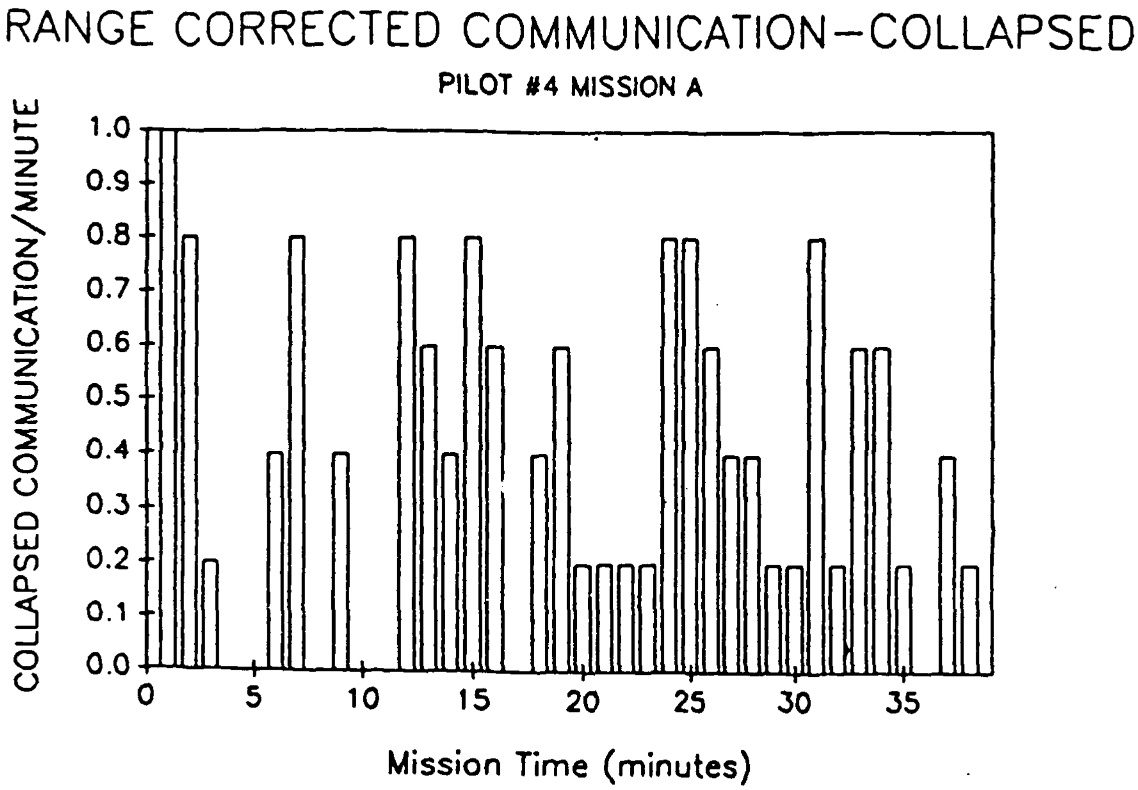

RANGE CORRECTED ERROR–COLLAPSED
PILOT #3 MISSION B
COLLAPSED ERROR/MINUTE
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
5
10
15
20
25
30
Mission Time (minutes)

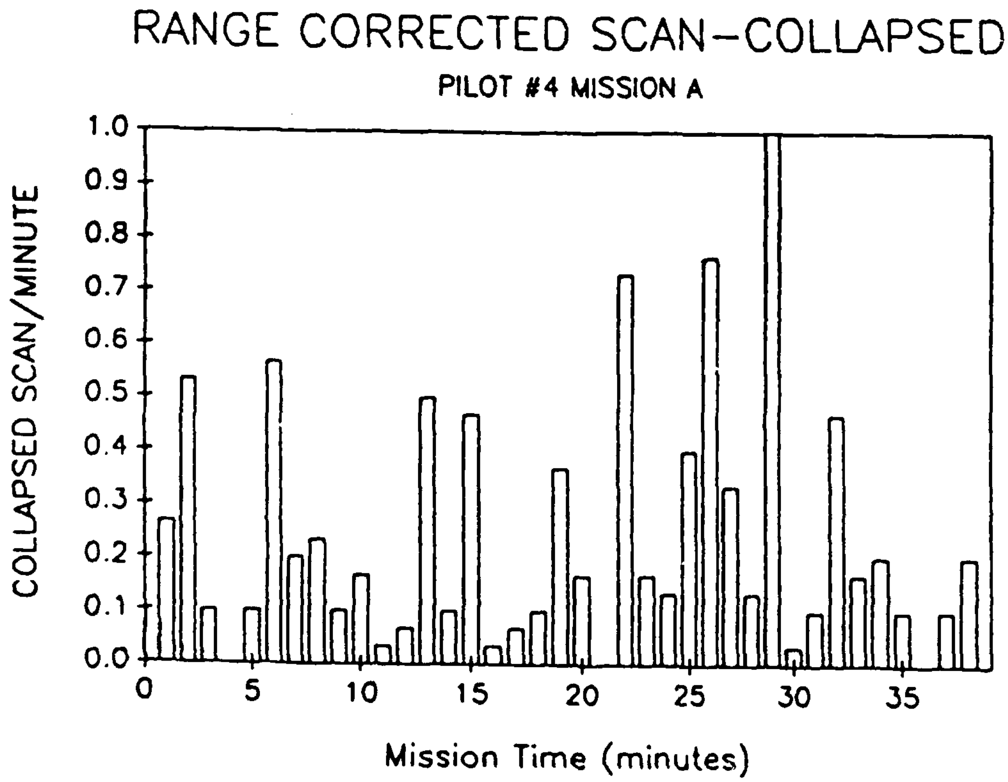

RANGE CORRECTED COMMUNICATION–COLLAPSED
PILOT #3 MISSION B
COLLAPSED COMMUNICATION/MINUTE
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
5
10
15
20
25
30
Mission Time (minutes)


RANGE CORRECTED SCAN–COLLAPSED
PILOT #3 MISSION B
COLLAPSED SCAN/MINUTE
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
5
10
15
20
25
30
Mission Time (minutes)


RANGE CORRECTED CONTROLS–COLLAPSED
PILOT #4 MISSION A
COLLAPSED CONTROL/MINUTE
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
5
10
15
20
25
30
35
Mission Time (minutes)

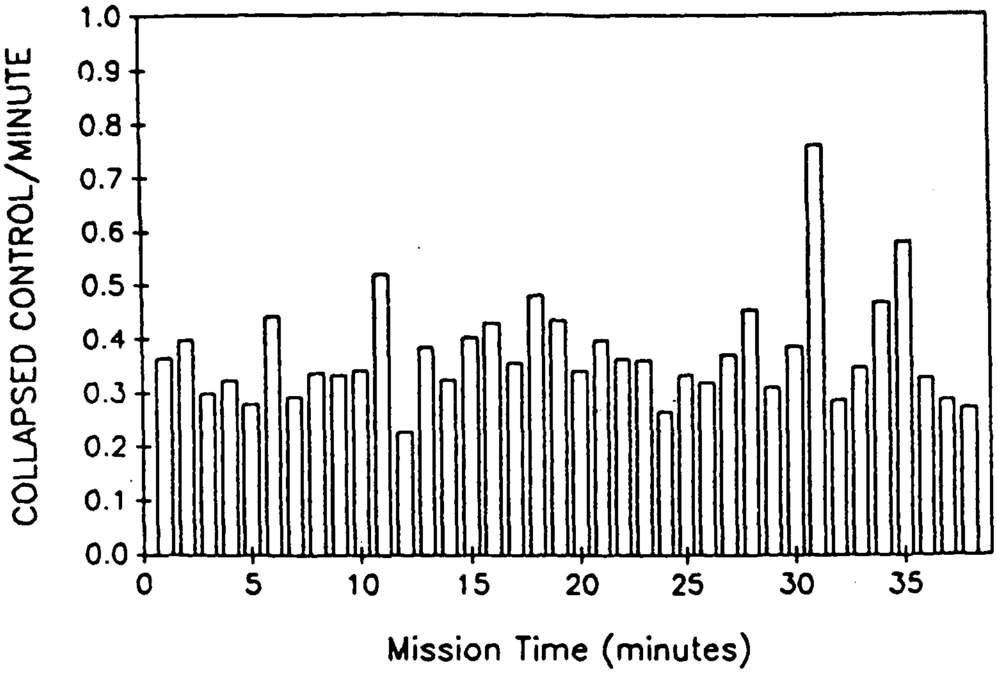

RANGE CORRECTED ERROR–COLLAPSED
PILOT #4 MISSION A
COLLAPSED ERROR/MINUTE
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
5
10
15
20
25
30
35
Mission Time (minutes)


RANGE CORRECTED COMMUNICATION–COLLAPSED
PILOT #4 MISSION A
COLLAPSED COMMUNICATION/MINUTE
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
5
10
15
20
25
30
35
Mission Time (minutes)


RANGE CORRECTED SCAN–COLLAPSED
PILOT #4 MISSION A
COLLAPSED SCAN/MINUTE
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
5
10
15
20
25
30
35
Mission Time (minutes)

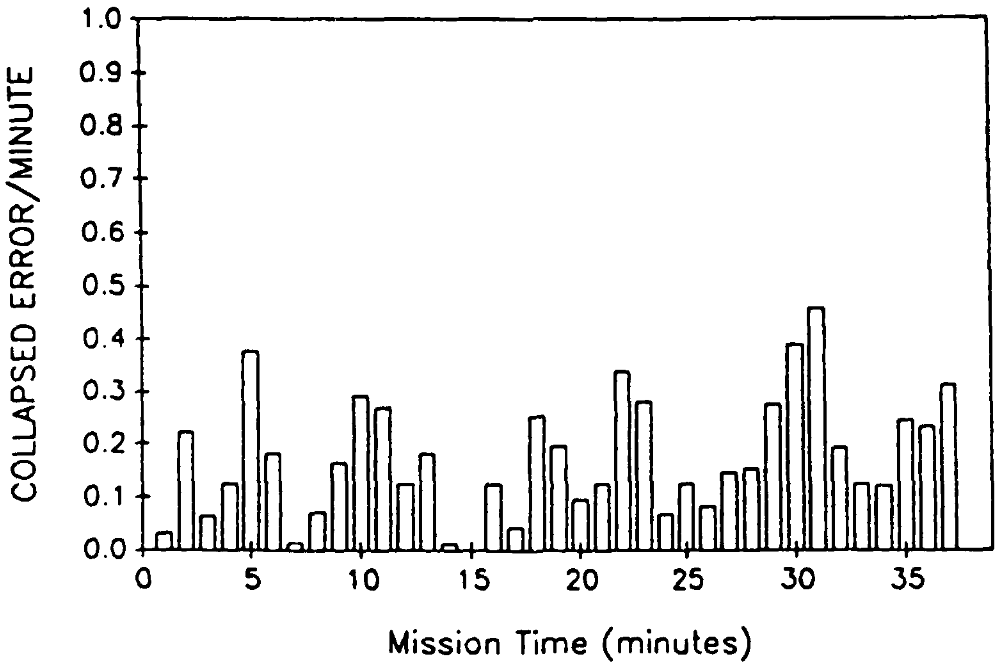
RANGE CORRECTED CONTROLS—COLLAPSED

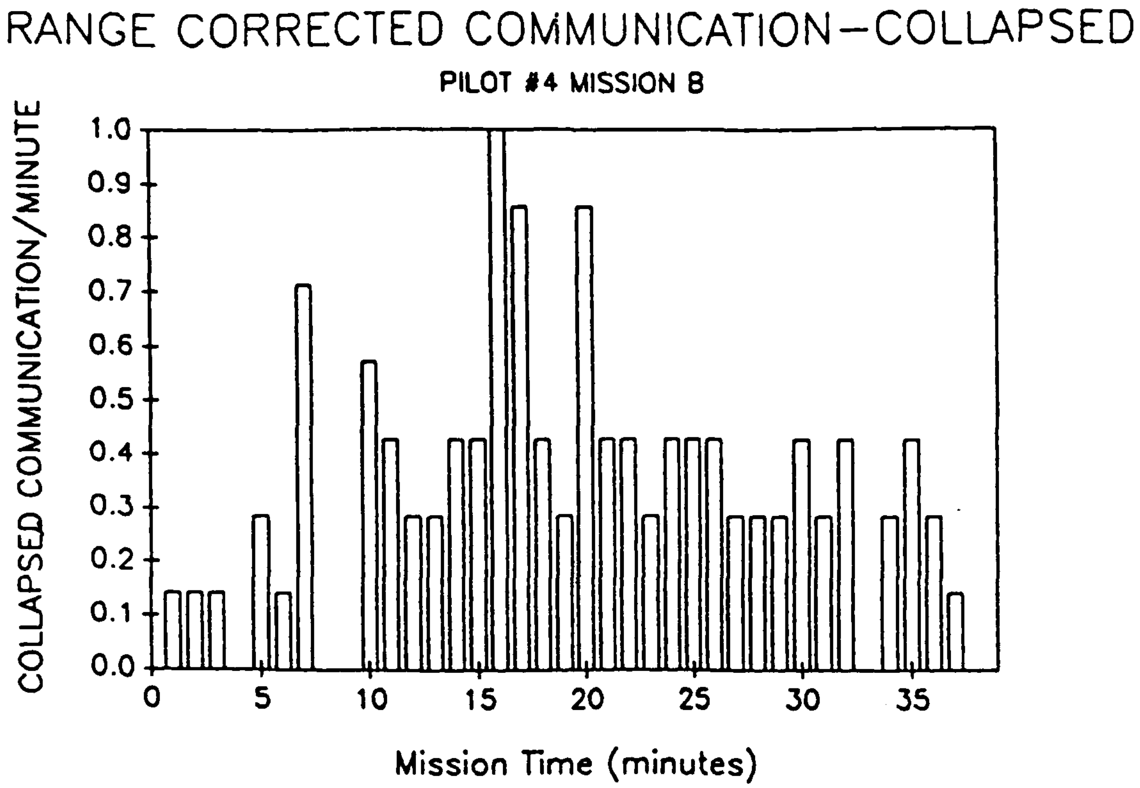
PILOT #4 MISSION B

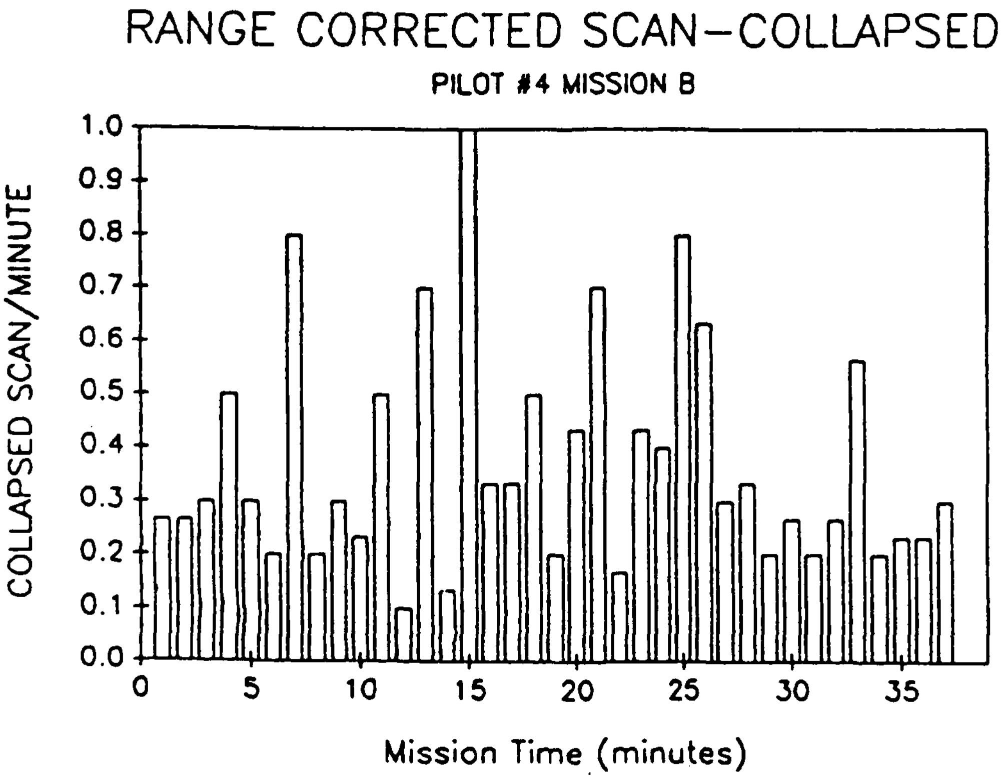


RANGE CORRECTED ERROR—COLLAPSED

PILOT #4 MISSION B

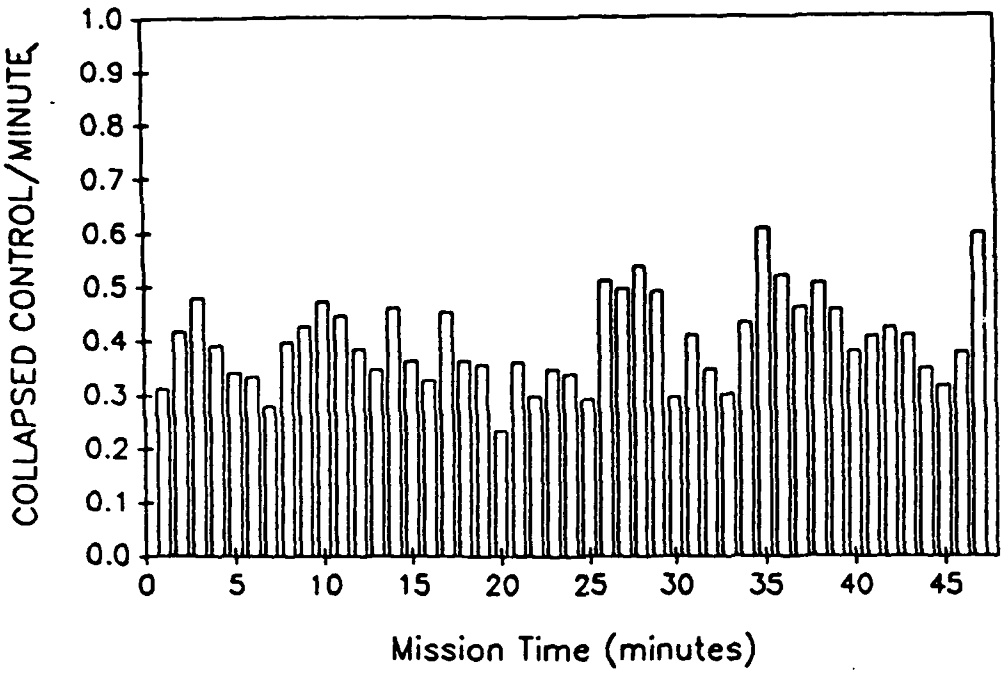



RANGE CORRECTED COMMUNICATION–COLLAPSED
PILOT #4 MISSION B
COLLAPSED COMMUNICATION/MINUTE
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
5
10
15
20
25
30
35
Mission Time (minutes)


RANGE CORRECTED SCAN–COLLAPSED
PILOT #4 MISSION B
COLLAPSED SCAN/MINUTE
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
5
10
15
20
25
30
35
Mission Time (minutes)

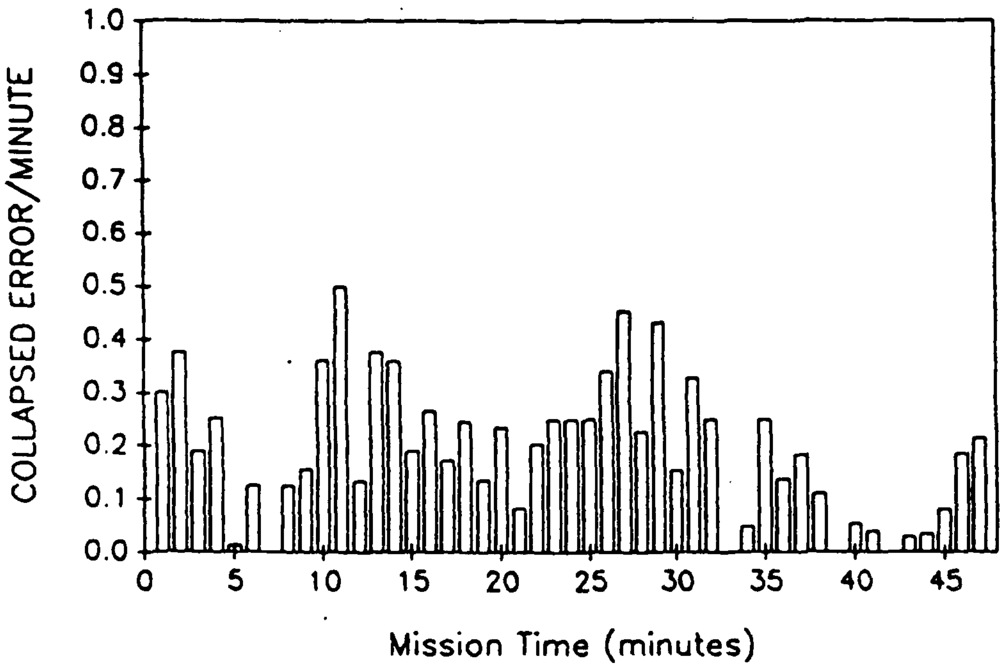
RANGE CORRECTED CONTROLS—COLLAPSED

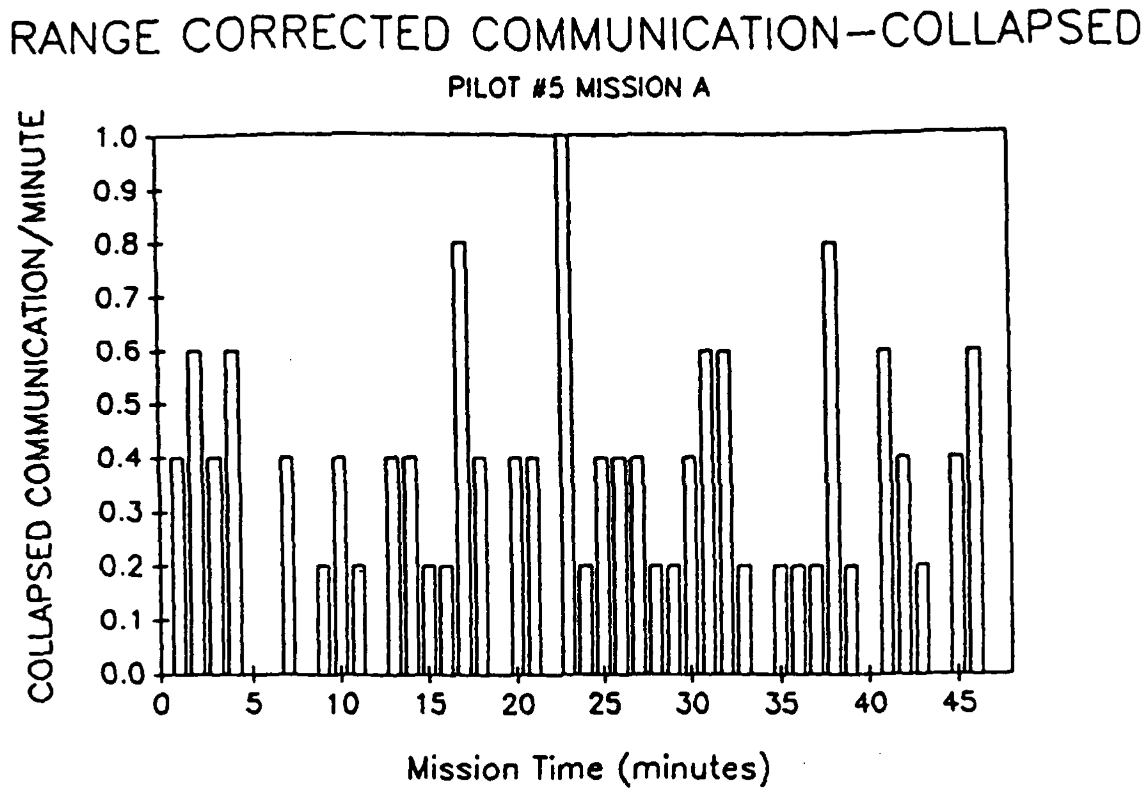
PILOT #5 MISSION A

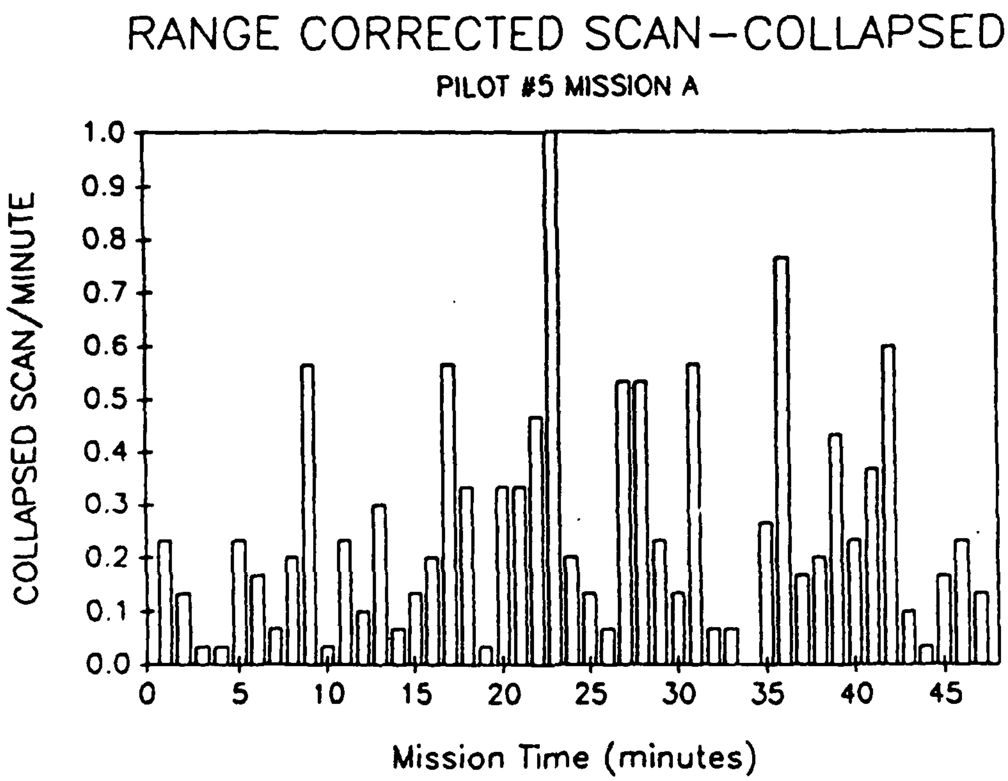


RANGE CORRECTED ERROR—COLLAPSED

PILOT #5 MISSION A

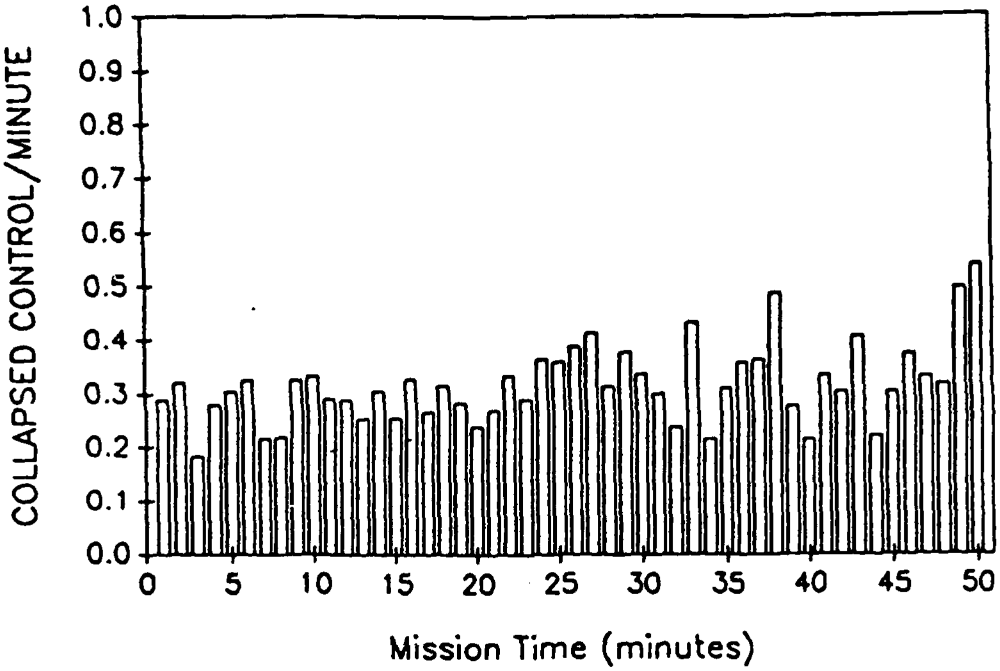



RANGE CORRECTED COMMUNICATION–COLLAPSED
PILOT #5 MISSION A
COLLAPSED COMMUNICATION/MINUTE
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
5
10
15
20
25
30
35
40
45
Mission Time (minutes)


RANGE CORRECTED SCAN–COLLAPSED
PILOT #5 MISSION A
COLLAPSED SCAN/MINUTE
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
5
10
15
20
25
30
35
40
45
Mission Time (minutes)

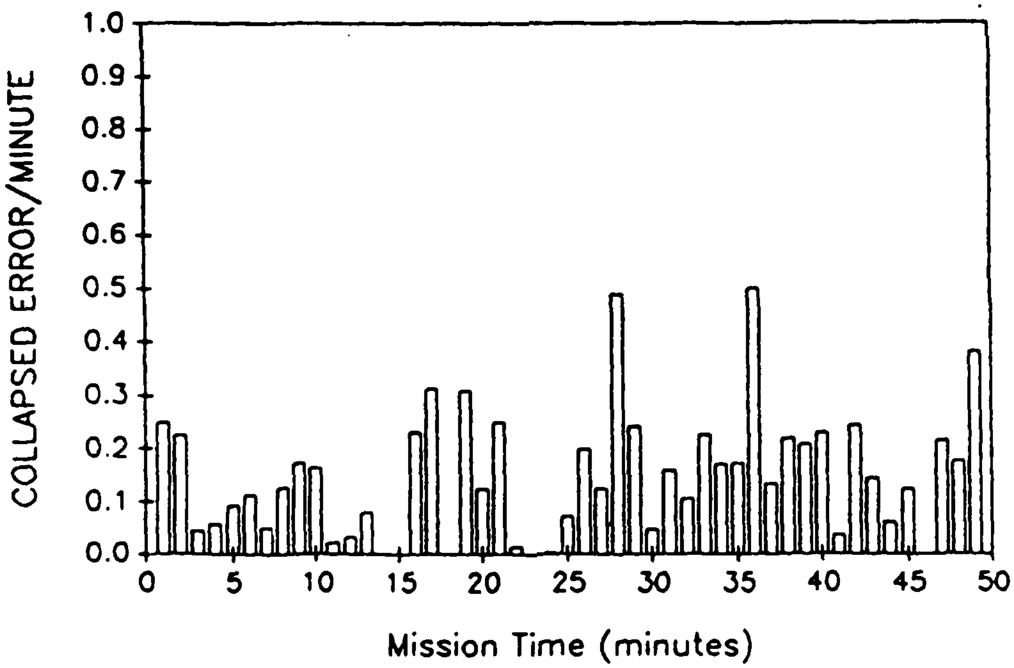
RANGE CORRECTED CONTROLS–COLLAPSED

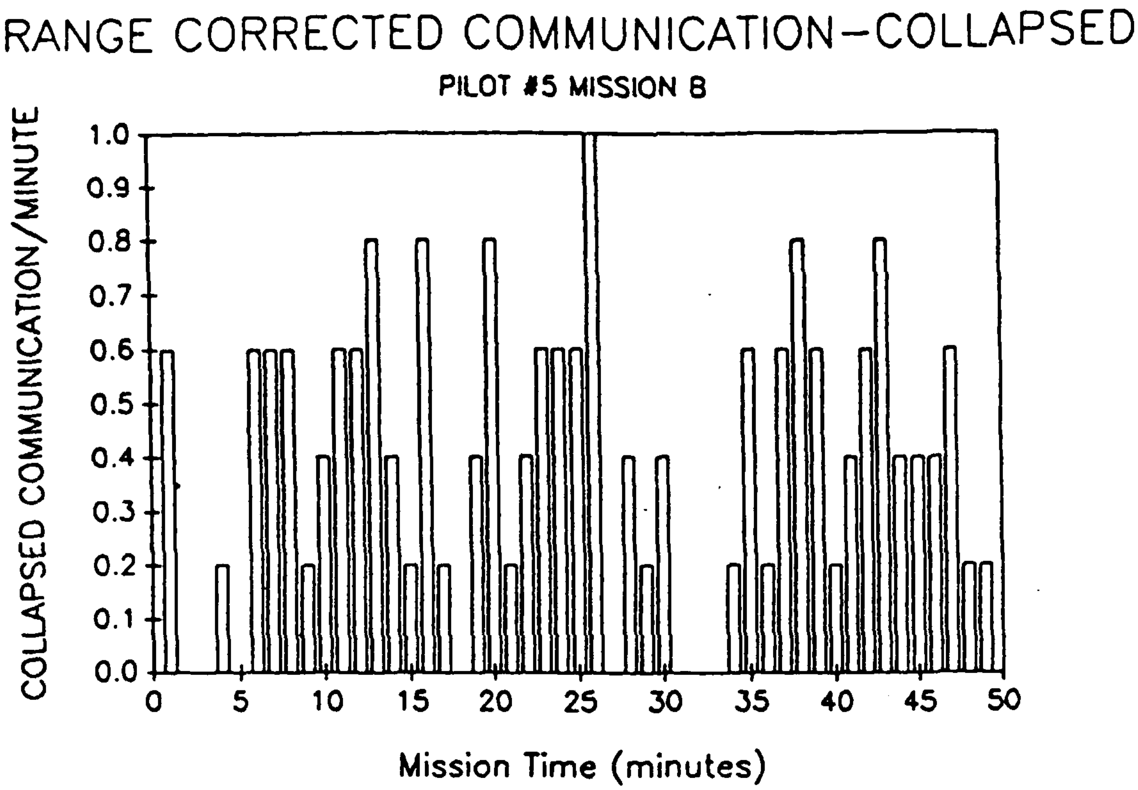
PILOT #5 MISSION B

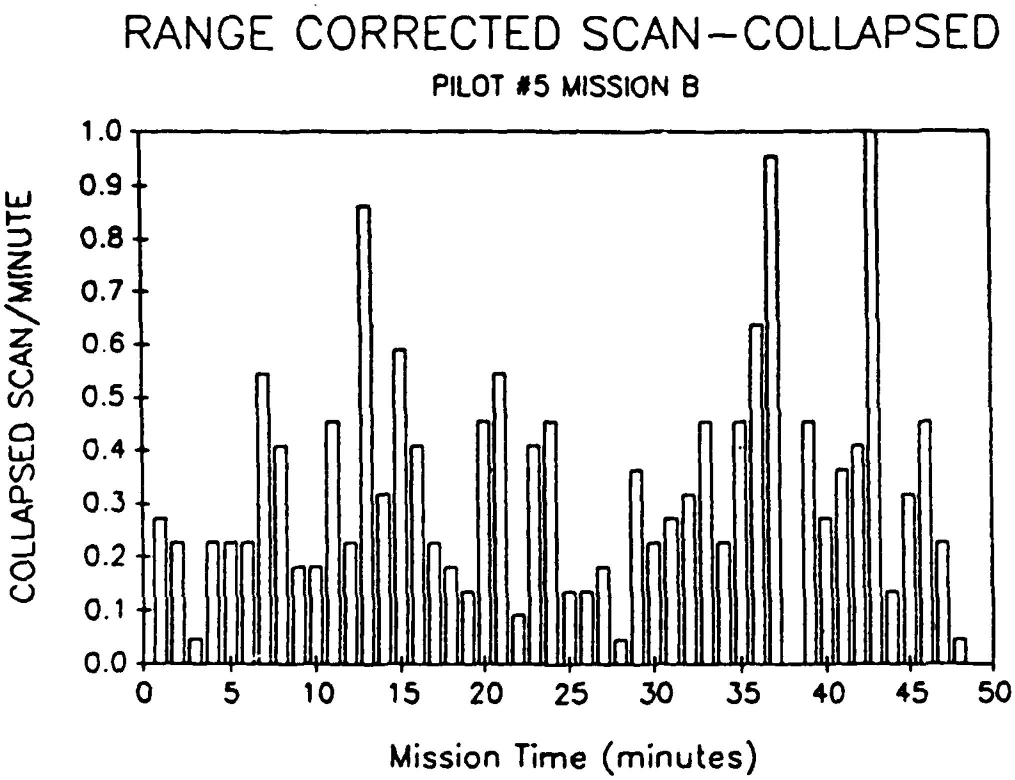


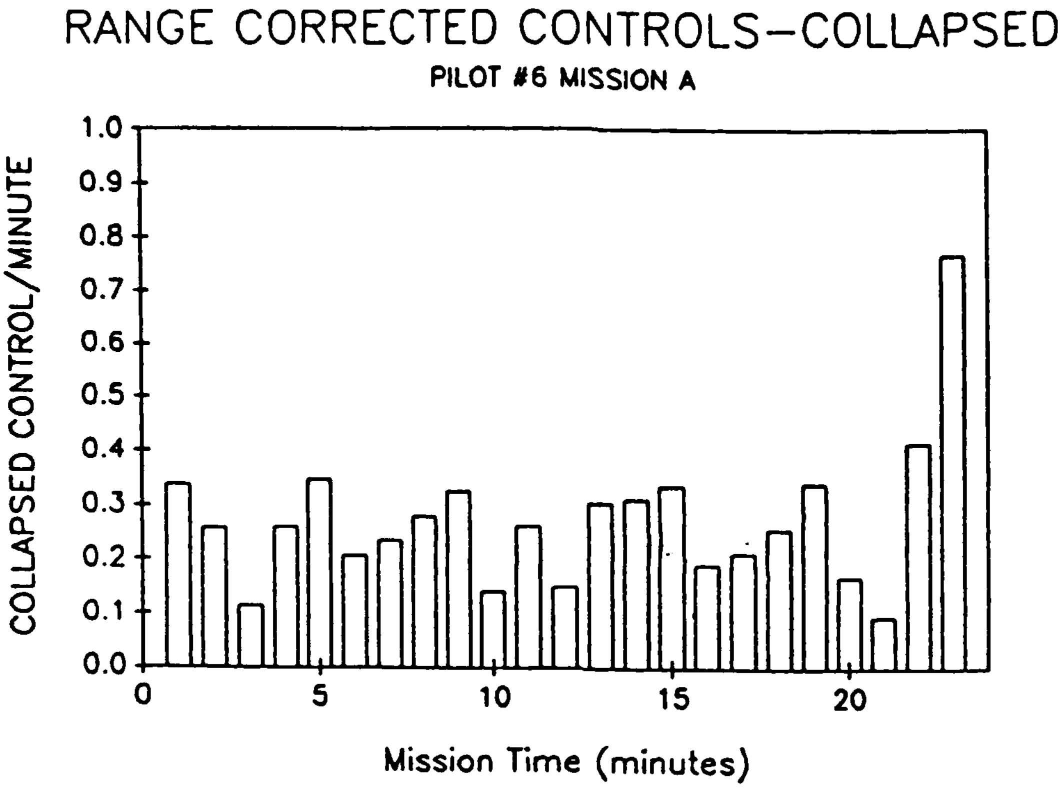
RANGE CORRECTED ERROR–COLLAPSED

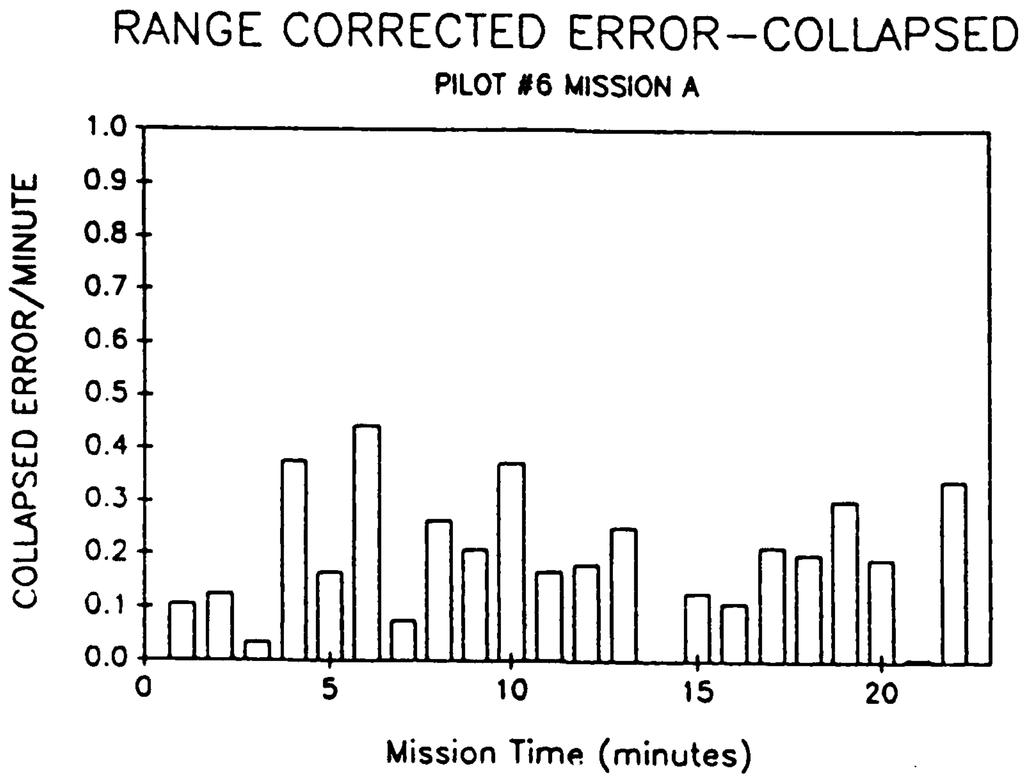
PILOT #5 MISSION B

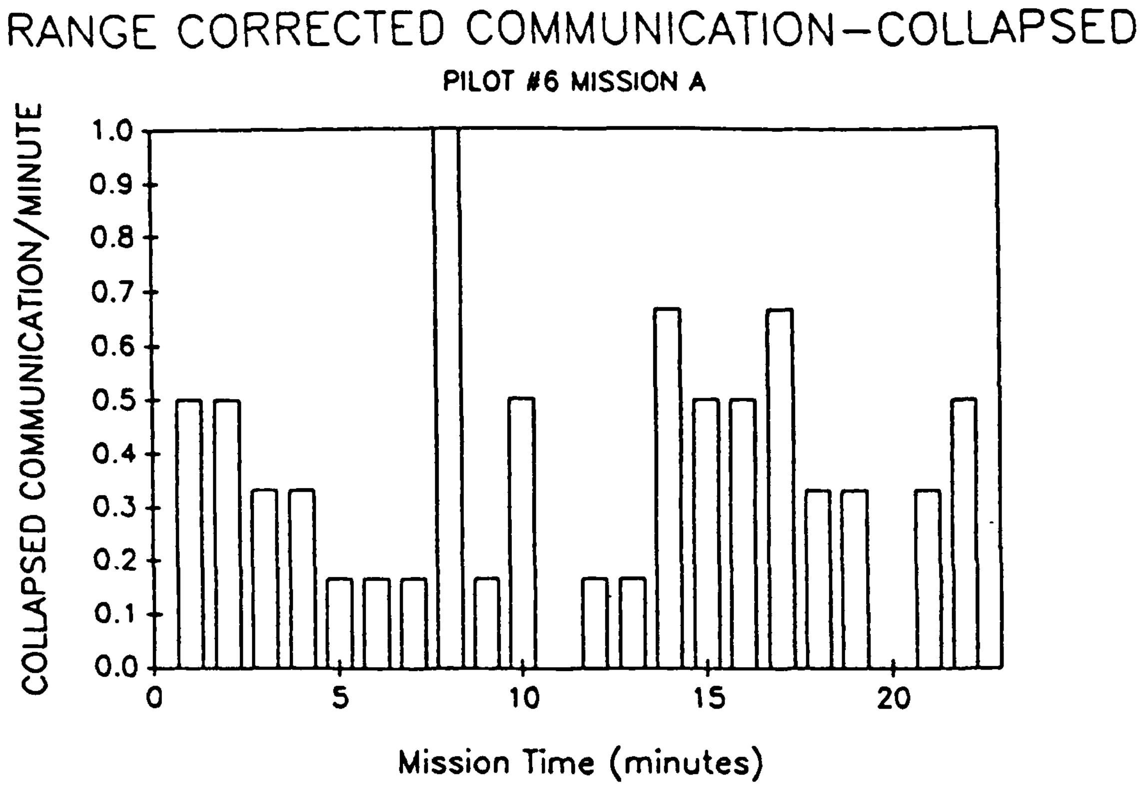


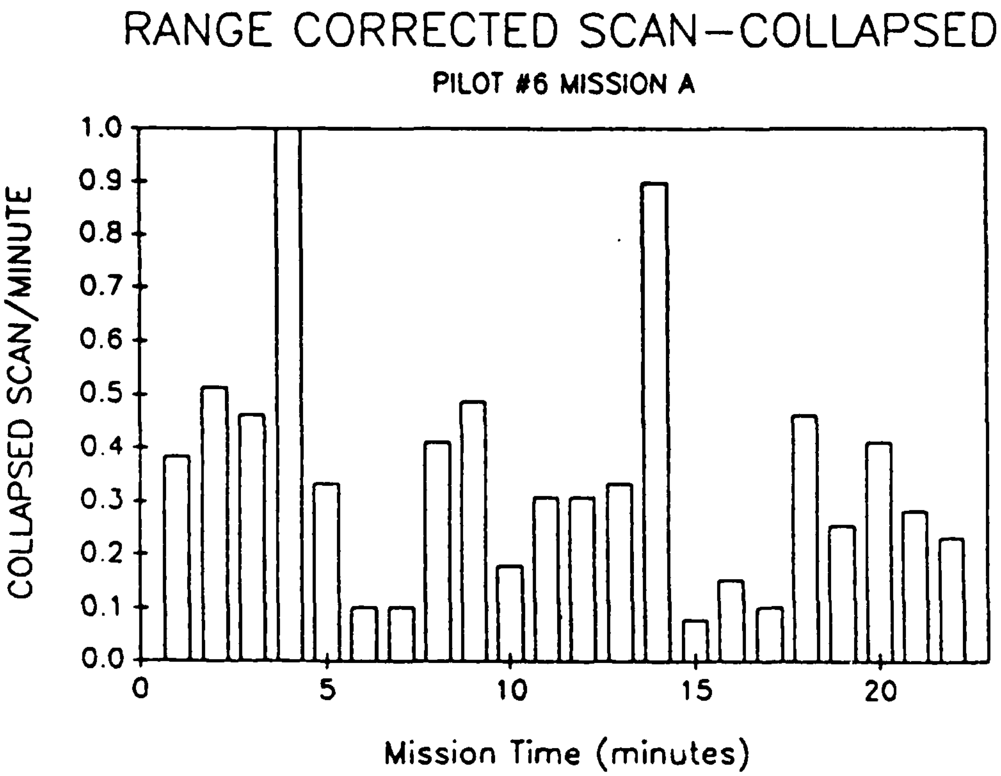

RANGE CORRECTED COMMUNICATION–COLLAPSED
PILOT #5 MISSION B
COLLAPSED COMMUNICATION/MINUTE
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
5
10
15
20
25
30
35
40
45
50
Mission Time (minutes)


RANGE CORRECTED SCAN–COLLAPSED
PILOT #5 MISSION B
COLLAPSED SCAN/MINUTE
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
5
10
15
20
25
30
35
40
45
50
Mission Time (minutes)


RANGE CORRECTED CONTROLS-COLLAPSED
PILOT #6 MISSION A
COLLAPSED CONTROL/MINUTE
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
5
10
15
20
Mission Time (minutes)

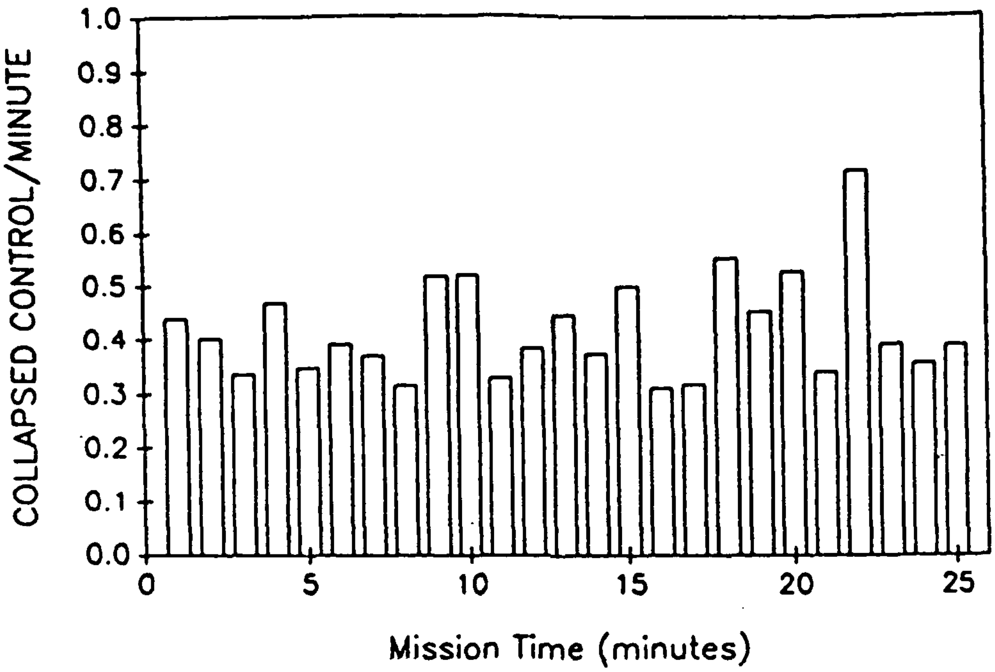

RANGE CORRECTED ERROR-COLLAPSED
PILOT #6 MISSION A
COLLAPSED ERROR/MINUTE
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
5
10
15
20
Mission Time (minutes)


RANGE CORRECTED COMMUNICATION–COLLAPSED
PILOT #6 MISSION A
COLLAPSED COMMUNICATION/MINUTE
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
5
10
15
20
Mission Time (minutes)


RANGE CORRECTED SCAN–COLLAPSED
PILOT #6 MISSION A
COLLAPSED SCAN/MINUTE
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
5
10
15
20
Mission Time (minutes)

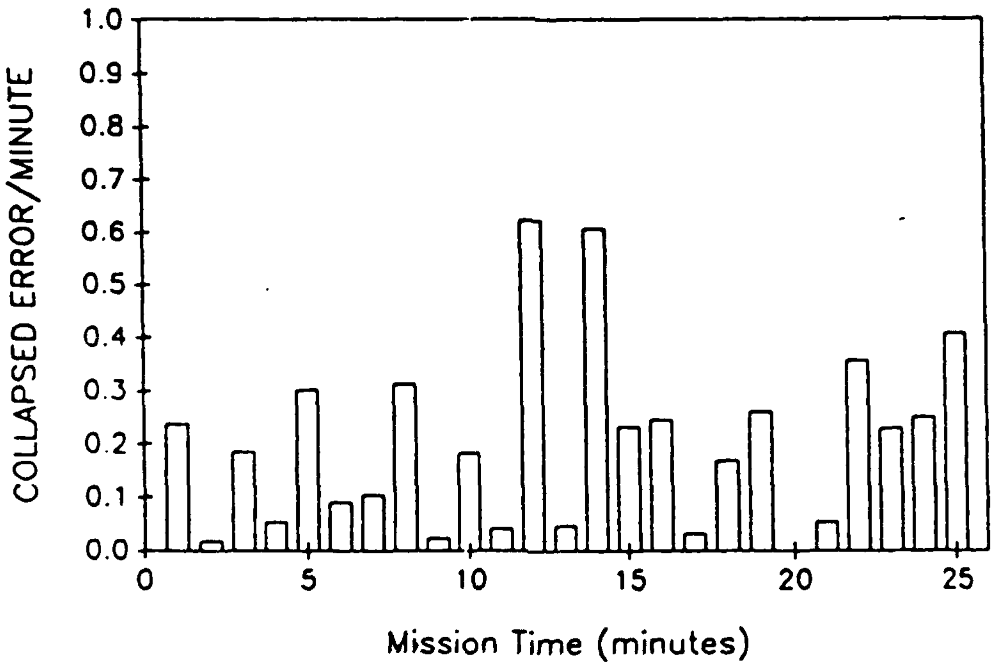
RANGE CORRECTED CONTROLS–COLLAPSED

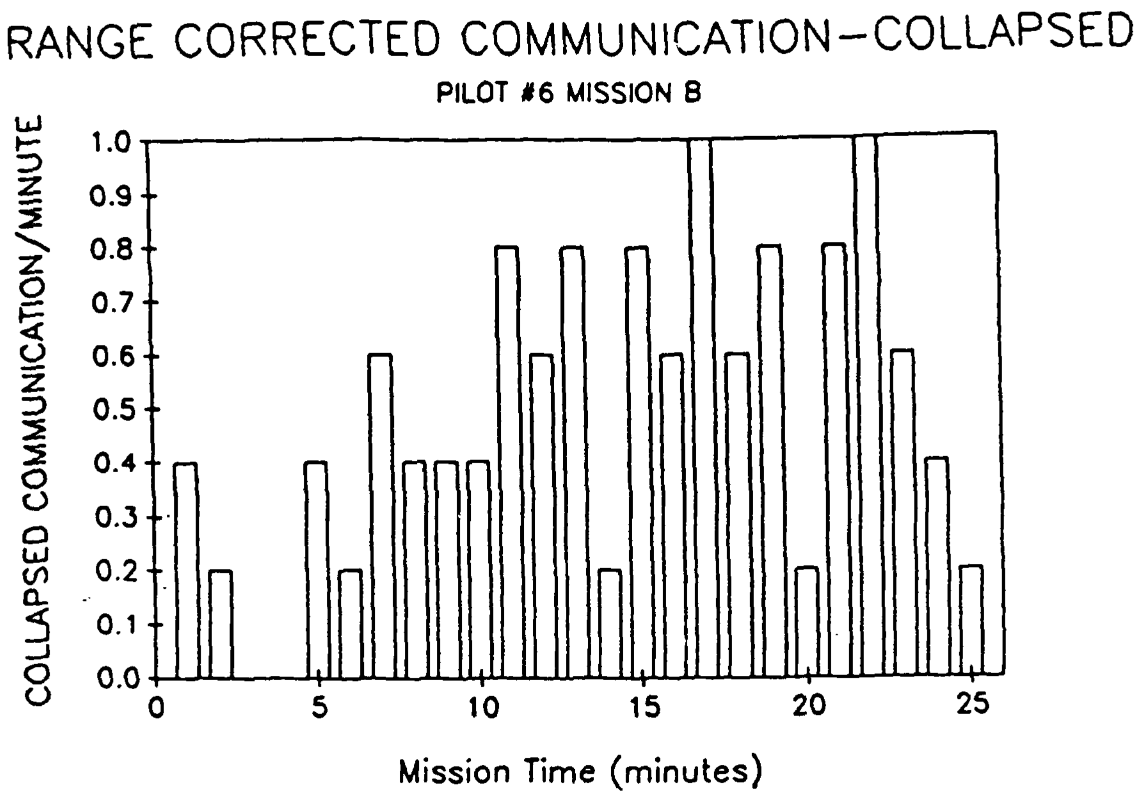
PILOT #6 MISSION B

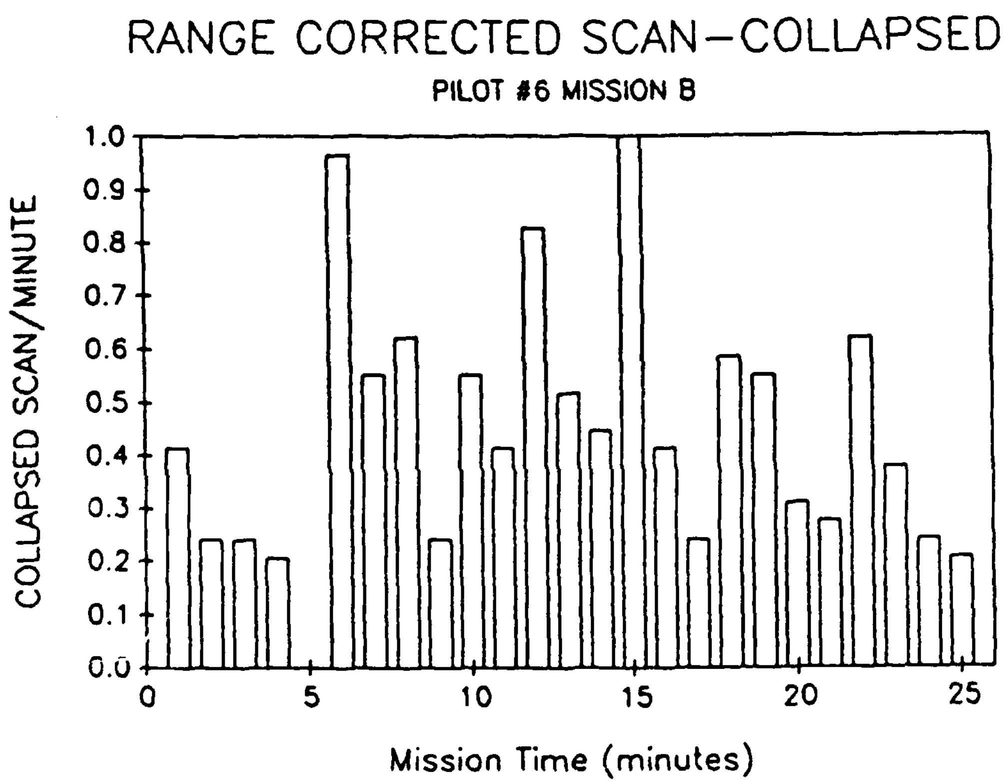


RANGE CORRECTED ERROR–COLLAPSED

PILOT #6 MISSION B




RANGE CORRECTED COMMUNICATION–COLLAPSED
PILOT #6 MISSION B
COLLAPSED COMMUNICATION/MINUTE
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
5
10
15
20
25
Mission Time (minutes)


RANGE CORRECTED SCAN–COLLAPSED
PILOT #6 MISSION B
COLLAPSED SCAN/MINUTE
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
5
10
15
20
25
Mission Time (minutes)

APPENDIX E

General Procedures for Global Measures

The global measures were derived by using the following procedure:

1) The raw scores of the variables that would make up the global measure for each pilot and mission on a minute by minute basis were range-corrected using the following equation:

$$\text{Corrected Score} = \frac{\text{Raw Score - Min of Score Distribution}}{\text{Maximum Score of the Distribution}}$$

2) The range-corrected scores of each variable, for a particular measure, were then summed and averaged. The resulting scores ranged from a minimum of 0 to a maximum of 1 for each measure.

3) These range-corrected collapsed scores were then plotted for each measure on a minute by minute basis for each pilot and mission (see Appendix D).

APPENDIX F

Computer Programs for Cardiovascular Measures

Spectral Analysis Program

```
PROCEDURE comspectra;

VAR
 buf1,
 buf2,
 buf3,
 buf4        (* arrays used in FFT *)                         : fftarray;
 smoar,      (* 'smooth array', array used for smoothing spectrum *)
 inter1,
 inter2,
 interim1,
 interim2,
 in1tot,
 in2tot      (* intermediate spectra *)                       : plotarray;
 varpoints,  (* total number of computing points (incl. overlaps) *)
 times,      (* loop-variable for loop across segments *)
 i,j,        (* loop variables *)
 noseg,      (* number of segments *)
 forget,     (* number of datapoints that should not be taken into account *)
 lastsam,    (* number of last sample in segment *)
 direc,      (* for FFT: -1: forward fft; +1: invers fft *)
 which,      (* indicates what kind of power should be computed, see HOWMUCH *)
 nopfft,     (* number of points in FFT *)
 nodfft,     (* number of real datapoints in FFT *)
 overlp,     (* (50%) overlap in segments *)
 nospct      (* number of spectral points *)                  : integer;
 variance,   (* variance of signal being analysed *)
 var1,       (* variance of signal 1 *)
 var2,       (* variance of signal 2 *)
 cor1,       (* correction factor for autospectrum 1 *)
 cor2        (* correction factor for autospectrum 2 *)   : real;

 PROCEDURE subtract (VAR dum : fftarray; VAR pointer : integer);

 VAR
  dc,slope,dummy,dummy1 : real;
  i : integer;

 BEGIN

  (* array 'dum' contains the datapoints of the segment we're working on;  *)
  (* 'pointer' is the number of datapoints in this segment.               *)

  dc    := 0.0;
  slope := 0.0;

  dummy := pointer;
  FOR i:=1 TO pointer DO
   BEGIN
    dc    := dc + dum[i]/dummy;
    slope := slope + i*dum[i]/dummy;
   END;
  (*                      n                           n            *)
  (* now dc = (1/n) * sum(x ) and slope = (1/n) * sum(i*x )   *)
  (*                    i=1  i                      i=1    i    *)


  slope:=(12.0*slope)/(sqr(dummy)-1.0)-6.0*dc/(dummy-1.0);

  (* remove dc-component and linear trend *)
  dummy1:= dc - 0.5 * (dummy+1.0) * slope;
  FOR i:=1 TO pointer DO dum[i]:=dum[i]-i*slope-dummy1;

 END; (* of procedure subtract *)
```

```
(* ---------------------------------------------------------------------

PROCEDURE cos10(VAR inar : fftarray; VAR lastone : integer);

VAR
 perc10 : integer;
 taper  :   real ;
 i      : integer;

BEGIN

 perc10 := lastone div 10;
 FOR i:=1 TO perc10 DO
  BEGIN
   taper := cos(i/perc10*pi/2.0);
   inar[perc10-i+1] := taper*inar[perc10-i+1];
   inar[lastone-perc10+i] := taper*inar[lastone-perc10+i];
  END;

END; (* of procedure cos10 *)

(* ---------------------------------------------------------------------

PROCEDURE fft (VAR realar, imar : fftarray ;VAR n, forwards : integer);

CONST
 ln2 = 0.6931471;

VAR
 ndiv2,
 radixconst,
 i,j,k,l,le,le1,ip : integer;
 constant,
 arg,
 mult,
 tempreal,tempim,
 costerm,sinterm   : real;

BEGIN

 (* initiate some variables *)
 ndiv2:=n div 2;
 constant:=forwards*2.0*pi;
 radixconst:=round(ln(n)/ln2);
 j:=1;le:=1;

 (* shuffle data by bit-reversing *)
 FOR i:=1 TO n-1 DO
  BEGIN
   IF i<j THEN
    BEGIN
     tempreal :=realar[j]; tempim :=imar[j];
     realar[j]:=realar[i]; imar[j]:=imar[i];
     realar[i]:=tempreal;  imar[i]:=tempim;
    END;
   k:=ndiv2;
   WHILE k<j DO
    BEGIN
     j:=j-k;
     k:=k div 2;
```

```
    END;
   j:=j+k;
  END; (* of data shuffling *)

 (* perform actual fft *)

 FOR l:=1 TO radixconst DO
  BEGIN
   le1:=le;
   le:=le*2;
   (* calculate butterflies *)
   FOR j:=1 TO le1 DO
    BEGIN
     arg:=constant*(j-1)/le;
     costerm:=cos(arg);
     sinterm:=sin(arg);
     i:=j;
     (* combine different stages *)
     REPEAT
      ip:=i+le1;
      tempreal   :=realar[ip]*costerm-imar[ip]*sinterm;
      tempim     :=realar[ip]*sinterm+imar[ip]*costerm;
      realar[ip]:=realar[i]-tempreal;
      imar[ip]   :=  imar[i]-tempim;
      realar[i]  :=realar[i]+tempreal;
      imar[i]    :=  imar[i]+tempim;
      i:=i+le;
     UNTIL i>=n;
    END; (* of butterfly calculation *)
  END;

END; (* of procedure fft *)

(* ------------------------------------------------------------------

PROCEDURE makesmoar (VAR inar1,inar2,inar3,inar4 : fftarray;
                     VAR hw : integer; VAR outar : plotarray);

VAR
 factor1,
 factor2    : integer;
 i,j,k      : integer;

FUNCTION howmuch (VAR in1,in2,in3,in4 : real) : real;

BEGIN

 CASE hw OF
 1: howmuch:=sqr(in1)+sqr(in2);
 2: howmuch:=sqr(in1)+sqr(in2);
 3: howmuch:=in1*in3+in2*in4   ;
 4: howmuch:=in1*in4-in2*in3
 END

END; (* of function howmuch *)

(* - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

BEGIN
```

```
outar[1]:=howmuch(inar1[1],inar2[1],inar3[1],inar4[1]); (* DC-component *)
FOR j:=2 TO nospct DO
 BEGIN
  outar[j]:=0.0;
  FOR k:=1 TO 3 DO
   BEGIN
    factor1:=2*j-(3-k);
    factor2:=2*(1+abs(2-k));
    outar[j]:=outar[j]+howmuch(inar1[factor1],inar2[factor1],
                              inar3[factor1],inar4[factor1])/factor2;
   END;
 END;

END; (* of procedure makesmoar *)

(* ---------------------------------------------------------------------- *)

PROCEDURE makearrays (VAR inar : dataarray; VAR outar1, outar2 : fftarray;
                      VAR outar3 : plotarray);

VAR
 mean : real;
 i,j  : integer;

BEGIN

 FOR j:=1 TO nodfft DO
  BEGIN
   outar1[j] := inar[(times-1)*overlp+j]          ; (* real part      *)
   outar2[j] := 0.0                               ; (* imaginary part *)
  END;

 (* dc- and trend-correction: *)
 (* 'lastsam' = number of samples in segment *)
 subtract(outar1,lastsam);

 (* compute mean and variance: *)
 mean     := 0.0;
 variance := 0.0;
 FOR j:=1 TO lastsam DO
  mean := mean + outar1[j];
 mean := mean / lastsam;
 FOR j:=1 TO lastsam DO
  variance := variance + sqr(outar1[j]-mean);

 (* tapering: *)
 cos10(outar1,lastsam);

 (* add zeroes ('zero-padding'): *)
 FOR j:=(nodfft+1) TO nopfft DO
  BEGIN
   outar1[j]:=0.0;
   outar2[j]:=0.0;
  END;

 (* do the fast fourier transform: *)
 (* 'direc' = direction of transformation : time -> frequency (direc = -1) *)
 (*           or frequency -> time (direc = +1); in this case: direc = -1  *)
 fft(outar1,outar2,nopfft,direc);
```

```
 (* make array which contains power for spectrum: *)
 (* 'which' = indication how the power should be computed (see HOWMUCH) *)
 which := 1;
 makesmoar(outar1,outar2,outar1,outar2,which,outar3);

END; (* of procedure makearrays *)

(* ------------------------------------------------------------------- *)

PROCEDURE compuphase;

VAR
 max,
 min,
 dummy,
 dumpy,
 criter        : real   ;
 locus         : integer;
 i,j           : integer;
BEGIN

  (* search for frequency with highest powerin second signal: *)
  max := 0.0;
  FOR i:=6 TO 50 DO
   IF autosp2[i]>max THEN
    BEGIN
     max    := autosp2[i];
     locus  := i;
    END;

  (* determine phasefunction for frequency at index 'locus': *)
  phasesp[locus] := arctan(in2tot[locus]/in1tot[locus]);

  (* determine phasefunction for frequencies lower than 'locus'-frequency: *)
  (* we work backwards from index 'locus-1' to '1' *)
  FOR i:=1 TO (locus-1) DO
   BEGIN
    criter := phasesp[locus-i+1];
    dummy  := arctan(in2tot[locus-i]/in1tot[locus-i]);
    min    := 100.0;
    FOR j:=1 TO 3 DO
     BEGIN
      dumpy := abs(dummy-(j-2)*2.0*pi-criter);
      IF dumpy<min THEN
       BEGIN
        min              := dumpy;
        phasesp[locus-i] := dummy-(j-2)*2.0*pi;
       END;
     END;
   END;

  (* determine phasefunction for frequencies higher than 'locus'-frequency:
  (* we work forwards from index 'locus+1' to 'nospct' *)
  FOR i:=1 TO (nospct-locus) DO
   BEGIN
    criter := phasesp[locus+i-1];
    dummy  := arctan(in2tot[locus+i]/in1tot[locus+i]);
    min    := 100.0;
    FOR j:=1 TO 3 DO
     BEGIN
```

```
      dumpy := abs(dummy-(j-2)*2.0*pi-criter);
      IF dumpy<min THEN
       BEGIN
        min               := dumpy;
        phasesp[locus+i] := dummy-(j-2)*2.0*pi;
       END;
     END;
   END;

  (* transform the phase-values from radials to degrees: *)
  FOR i:=1 TO nospct DO
   phasesp[i] := phasesp[i]*180.0/pi;

END; (* of procedure compuphase *)

(* ---------------------------------------------------------------------- *)

(* ------------------------- TOTPOWER ------------------------------ *)
(*                                                                        *)
(* This function (a subfunction within COMSPECTRA) computes a correction  *)
(* factor for the spectrum in 'inar', so that the total power = total     *)
(* variance.                                                              *)
(*                                                                        *)

FUNCTION totpower (VAR inar : plotarray) : real;

VAR
 sumpower : real ;
 j        : integer;

BEGIN

 sumpower := 0.0;
 FOR j:=2 TO nospct DO sumpower := sumpower + inar[j];
 totpower := sumpower/100.0;

END; (* of function totpower *)

(* ----------------------------------------------------------------------

 BEGIN (* of comspectra *)

  direc := -1; (* direction for fft: from time domain to frequency domain *)

  var1 := 0.0; (* variance for signal 1, for scaling the spectra *)
  var2 := 0.0; (* variance for signal 2, for scaling the spectra *)

  nopfft := nosamp;              (* number of datapoints in FFT       *)
  nodfft := round(nopfft/2);     (* number of real datapoints in FFT *)
  overlp := round(nodfft/2);     (* 50% overlap in segments           *)
  nospct := nopoint;             (* number of spectral points         *)

  (* compute the number of segments (50 % overlap): *)
  (* 'last' = total number of datapoints *)
  i := 1;
  WHILE ((last-((i-1)*overlp+nodfft))>round(0.5*overlp)) DO i:=i+1;
  noseg := i;

  (* throw away datapoints following the end of the last segment: *)
  (* 'forget' = number of points to be thrown away *)
```

```
forget := last-(noseg-1)*overlp-nodfft;
IF (forget>0) THEN
 BEGIN
  last:=last-forget;
  FOR i:=(last+1) TO maxdata DO
   BEGIN
    input1[i]:=0;
    input2[i]:=0;
   END;
 END;

(* compute the total number of computation points (including overlaps),
(* for determing the variances:
varpoints := last + (noseg-1)*overlp;

(* initialize the spectrum-arrays: *)
FOR i:=1 TO nospct DO
 BEGIN
  autosp1[i] := 0.0;
  autosp2[i] := 0.0;
  in1tot[i]  := 0.0;
  in2tot[i]  := 0.0;
 END;

(* main loop across the segments: *)

FOR times:=1 TO noseg DO

 BEGIN

  (* compute number of actual datapoints in segment(times): *)
  IF times = noseg
  THEN (* last segment *) lastsam := last - (times-1)*overlp
  ELSE lastsam := nodfft;

  (* compute segment-autospectrum for first signal: *)
  makearrays(input1,buf1,buf2,inter1);
  var1 := var1 + variance/varpoints;

  IF mode>2 THEN (* there are two signals involved *)
   BEGIN

    (* compute segment-autospectrum for second signal: *)
    makearrays(input2,buf3,buf4,inter2);
    var2 := var2 + variance/varpoints;

    (* compute first interim spectrum for determining  *)
    (* coherence, transfer and phase functions:        *)
    which := 3;
    makesmoar(buf1,buf2,buf3,buf4,which,interim1);

    (* compute second interim spectrum for determining *)
    (* coherence, transfer and phase functions:        *)
    which := 4;
    makesmoar(buf1,buf2,buf3,buf4,which,interim2);

   END; (* of mode>2 *)

  (* now add this segment to the totals: *)
```

```
  FOR j:=1 TO nospct DO
   autospl[j] := autospl[j] + interl[j]/noseg;

  IF mode>2 THEN
   FOR j:=1 TO nospct DO
    BEGIN
     autosp2[j] := autosp2[j] + inter2[j]  /noseg;
     in1tot[j]  := in1tot[j]  + interim1[j]/noseg;
     in2tot[j]  := in2tot[j]  + interim2[j]/noseg;
    END;

 END; (* of times loop *)


(* compute correction factors and determine definite *)
(* spectra and functions:                            *)

cor1 := var1/totpower(autospl);
FOR j:=1 TO nospct DO autospl[j] := autospl[j]*cor1;

IF mode>2 THEN
 BEGIN
  cor2 := var2/totpower(autosp2);
  FOR j:=1 TO nospct DO
   BEGIN
    autosp2[j] := autosp2[j]*cor2;
    cohersp[j] := (sqr(in1tot[j])+sqr(in2tot[j]))/(autospl[j]*autosp2[j]);
    cohersp[j] := cohersp[j]*(cor1*cor2);
    tranfsp[j] := 1000.0*(cohersp[j]*autospl[j])/autosp2[j];
   END;
  compuphase; (* determine phase function *)
 END;

END; (* of procedure comspectra *)
```

R-Wave Detection, IBI, and T-Wave Amplitude Programs

```
 (*-----------------------------------------------------------*)
procedure findit;

var
 meani,meant,xsum,ysum,zsum : real;
 found,stop,allcor                  : boolean;
 ntotal,i,j,k,hold1,hold2,max,sum,iwave,diff,last,nosam,
 skip,itot,mid,
 point1,point2,now,start,icor  : integer;
 keep : longint;
 rkeep,rpnt1,rpnt2 : real;
 peak,slope,mean,corfac,amp,base,amax,oldslope,newslope,
 lapeak,firibi,secibi,time,total,rdiff: real;


begin (* findit *)

 reset(heartfile);

 now:=0;
 keep:=0;
 start:=0;
 sec_Number := 0;

 while not(eof(heartfile)) do
  begin

    delay(2000);
    writeln('Reading seconds ',sec_Number:8,' to ',sec_Number + 5);
    sec_Number := sec_Number + 5;

    if start>0 then
     for i:=1 to start do
      heartar[i]:=heartar[1000-start+i];

 (* read in (1000-start) samples *)
    ntotal:=start;
    for i:=(start+1) to 1000 do
```

```
    if (not(eof(heartfile))) then
      begin
       read(heartfile,heartar[i]);
       if (eoln(heartfile)) then readln(heartfile);
       ntotal:=ntotal+1;
      end;

  i:=2;
  WHILE (I<(NTOTAL-100)) DO
   BEGIN
    FOUND:=FALSE;
    IF (HEARTAR[I]>Schmitt_Level) THEN FOUND:=TRUE;

   if found then (* R-wave has been detected; determine its peak
latency *)
     begin

      POINT1:=I;
      STOP:=FALSE;

      FOR K:=1 TO 10 DO
       IF NOT(STOP) THEN
        IF (HEARTAR[I+K-1]>Schmitt_level) THEN
          J:=K
        ELSE
         STOP:=TRUE;

      POINT2:=POINT1+J-1;

(* DETERMINE MAXIMUM SLOPE IN LOCAl neighborhood *)
 amax:=0.0;
 mid:=round((point1+point2)/2.0);

 for k:=1 to 12 do
  begin
   if (mid-k)>1 then
    if (abs(heartar[mid-k+1]-heartar[mid-k])>amax) then
      amax:=abs(heartar[mid-k+1]-heartar[mid-k]);
   if (mid+k)<ntotal then
    if (abs(heartar[mid+k]-heartar[mid+k-1])>amax) then
      amax:=abs(heartar[mid+k]-heartar[mid+k-1]);
  end;
  newslope:=amax;

(* the two points that lie to the left and the right of the peak have
been determined. Now determine the peak latency *)

{      peak:=5.0*(keep+(point2+point1)/2.0); }

      rkeep := keep * 1.0;
      rpnt1 := point1 * 1.0;
      rpnt2 := point2 * 1.0;
      peak:=5.0*(rkeep+(rpnt2+rpnt1)/2.0);


(* take the first R-wave only if it occurred more than 200 ms after
   the beginning of the epoch *)

      if (peak>200.0) then
       IF ((NOW>0) AND ((PEAK-IBI[NOW])<400.0)) THEN
```

```
        BEGIN
          IF (NEWSLOPE<OLDSLOPE) THEN NOW:=NOW;
        END
       ELSE
        begin
           now:=now+1;
           ibi[now]:=peak;
           OLDSLOPE:=NEWSLOPE;
           writeln('Found R-Wave # ',now:8,' IBI = ',ibi[now]:10:1);
        end;

      i:=i+40;
     end
    else
     i:=i+1;
   END; (* OF I- WHILE LOOP *)

    start:=1000-(i-2);
    keep:=keep+(i-2);

  end; (* of grand while loop *)


  firibi:=ibi[1];
  secibi:=ibi[1];

  for i:=1 to (now-1) do
   ibi[i]:=ibi[i+1]-ibi[i];

  allcor:=false;
  while not(allcor) do
   begin
    allcor:=true;
    mean:=0.0;
    for i:=1 to (now-1) do
     mean:=mean+ibi[i]/(now-1);

    for i:=1 to (now-1) do
     begin

     if (ibi[i]<(0.6*mean)) then (* too small IBI; add it to
a left or right IBI *)
      begin
       if (i=1) then
        begin
         allcor:=false;
         firibi:=firibi+ibi[1];
         secibi:=secibi+ibi[1];
         now:=now-1;
         for j:=1 to (now-1) do
          ibi[j]:=ibi[j+1];
        end
       else
        if (i<>(now-1)) then
         if ((ibi[i-1]<(0.7*mean)) or (ibi[i+1]<(0.7*mean))) then
          if (ibi[i-1]<ibi[i+1]) then
            begin
             allcor:=false;
             ibi[i-1]:=ibi[i-1]+ibi[i];
             now:=now-1;
```

```
              for j:=i to (now-1) do
               ibi[j]:=ibi[j+1];
             end
           else
             begin
              allcor:=false;
              ibi[i]:=ibi[i]+ibi[i+1];
              now:=now-1;
              for j:=(i+1) to (now-1) do
               ibi[j]:=ibi[j+1];
             end
          else
           if ((ibi[i-1]>(1.2*mean)) or (ibi[i+1]>(1.2*mean))) then
            if (ibi[i-1]>ibi[i+1]) then
             begin
              allcor:=false;
              ibi[i-1]:=ibi[i-1]+ibi[i];
              now:=now-1;
              for j:=i to (now-1) do
               ibi[j]:=ibi[j+1];
             end
           else
             begin
              allcor:=false;
              ibi[i]:=ibi[i]+ibi[i+1];
              now:=now-1;
              for j:=(i+1) to (now-1) do
               ibi[j]:=ibi[j+1];
             end;
         end;
       end;
      end;

   allcor:=false;
   while not(allcor) do
    begin
     allcor:=true;
     mean:=0.0;
     for i:=1 to (now-1) do
      mean:=mean+ibi[i]/(now-1);

     for i:=1 to (now-1) do
      begin


      icor:=round(ibi[i]/mean);
      if (icor>1) then
       begin
        allcor:=false;
        if (i=1) then
         begin
          now:=now+icor-1;
          for j:=(now-1) downto (icor+1) do
           ibi[j]:=ibi[j-(icor-1)];
          for j:=icor downto 1 do
           ibi[j]:=ibi[1]/icor;
         end
        else
         if (i=now) then
          begin
```

```
          for j:=icor downto 1 do
           ibi[j-1+now-1]:=ibi[now-1]/icor;
          now:=now+icor-1;
         end
        else
         begin
          dumibi[1]:=ibi[i];
          now:=now+icor-1;
          for j:=(now-1) downto (i+icor) do
           ibi[j]:=ibi[j-(icor-1)];
          for j:=i to (i+(icor-1)) do
           ibi[j]:=dumibi[1]/icor;
         end;
        end;
       end;
      end;

      now:=now-1;  (* to make sure that reading won't go out of bound:

 (* Now determine the amplitude of the T-wave.
First compute the baseline over 80-50 ms before R-wave. Then, compute
the maximum amplitude over the interval 50 ms after the r-wave till
80 ms before the next one. *)

      reset(heartfile);
      for i:=1 to (round((firibi-80.0)/5.0)-1) do
       read(heartfile,j);
      last:=0;
      total:=0.0;

      for iwave:=1 to (now-1) do
       begin
        total:=total+ibi[iwave];
        nosam:=round(total/5.0);
        if (total>60000.0) then
         begin
          total:=total-60000.0;
          last:=last-round(60000.0/5.0);
          nosam:=nosam-round(60000.0/5.0);
         end;
     (* read in the samples *)
        diff:=nosam-last;
        last:=nosam;
        for i:=1 to  diff do
         read(heartfile,sear[i]);
        sum:=0;
        for k:=1 to 6 do
         sum:=sum+sear[k];
        sum:=round(sum/6.0);
        max:=-3000;
        for k:=26 to  diff do
         if (sear[k]>max) then
          begin
           max:=sear[k];
           keep:=k;
          end;
        max:=0;
        for k:=1 to 5 do
         max:=max+sear[keep+k-3];
        max:=round(max/5.0)-sum;
```

```
       twave[iwave]:=max;
      end;

     meani:=0.0;
     meant:=0.0;
     xsum:=0.0;
     ysum:=0.0;
     zsum:=0.0;
     for i:=1 to (now-1) do
      begin
       meani:=meani+ibi[i]/(now-1);
       meant:=meant+twave[i]/(now-1);
      end;
      for i:=1 to (now-1) DO
       begin
        xsum:=xsum+(ibi[i]-meani)*(twave[i]-meant);
        ysum:=ysum+(ibi[i]-meani)*(ibi[i]-meani);
        zsum:=zsum+(twave[i]-meant)*(twave[i]-meant);
       end;
      xsum:=xsum/sqrt(ysum*zsum);
      writeln(' correlation HR-Twave amp =',xsum:7:5);


  assign(outfile,paramstr(2) + '.IBI' );
  rewrite(outfile);

  assign(out2file,paramstr(2) + '.TWV' );
  rewrite(out2file);


  for i:=1 to (now-1) do
   begin
    if (i=1) then totibi[i]:=ibi[i]
    else
     totibi[i]:=totibi[i-1]+ibi[i];
    write(outfile,ibi[i]:8:1);
    write(out2file,twave[i]:8);
    if (i mod 10)=0 then
     begin
      writeln(outfile);
      writeln(out2file);
     end;
   end;
  peak:=0.0;
  writeln(outfile,peak:8:1);
  writeln(out2file,round(peak):8);
  close(outfile);
  close(out2file);

  firibi:=ibi[1]/2.0;

(* now construct the file with twave amplitudes. For this, we start
at point firibi and take every 400 ms a sample. The sample value is
determined by simple intrapolation *)

 assign(tfile,paramstr(2) + '.TRS' );
 rewrite(tfile);

 i:=1;
 j:=1;
```

```
while ((firibi+(i-1)*400.0)<totibi[now-1]) do
 begin
  time:=firibi+(i-1)*400.0;
  while (totibi[j]<time) do j:=j+1;
  if j=1 then
   twavam[i]:=twave[j]
  else
   twavam[i]:=(twave[j-1]*(time-totibi[j-1])+
             twave[j]*(totibi[j]-time))/(totibi[j]-totibi[j-1]);
  write(tfile,twavam[i]:8:1);
  if (i mod 10)=0 then writeln(tfile);
  i:=i+1;
 end;
 writeln(tfile,peak:8:1);

 close(tfile);

(* Finally, read in the respiration data; starting from point
 secibi and ending at point totibi[now-1] *)

 assign(respfile,paramstr(2) + '.RES' );
 rewrite(respfile);

 secibi:=secibi+ibi[1]/2.0;
 for i:=1 to (round(secibi/5.0)-5) do
  read(respinfil,j);
 rdiff:=totibi[now-1]-secibi+100.0;
 j:=0;
 while ((j+1)*10000.0)<rdiff do j:=j+1;
 rdiff:=rdiff-j*10000.0;
 keep:=0;
 skip:=0;
 xsum:=0.0;
 itot:=0;
 for i:=1 to j do
  for k:=1 to 2000 do
   begin
      read(respinfil,diff);
      if skip=0 then
       begin
        keep:=keep+1;
        xsum:=xsum+diff;
        if keep=11 then
         begin
          write(respfile,(xsum/11.0):8:1);
          itot:=itot+1;
          if (itot mod 10)=0 then writeln(respfile);
          skip:=1;
          keep:=0;
          xsum:=0.0;
         end;
       end
      else
       begin
        skip:=skip+1;
        if skip=70 then skip:=0;
       end;
   end;
 for i:=1 to round(rdiff/5.0) do
  begin
```

```
      read(respinfil,diff);
      if skip=0 then
       begin
        keep:=keep+1;
        xsum:=xsum+diff;
        if keep=11 then
         begin
          write(respfile,(xsum/11.0):8:1);
          itot:=itot+1;
          if (itot mod 10)=0 then writeln(respfile);
          skip:=1;
          keep:=0;
          xsum:=0.0;
         end;
       end
      else
       begin
        skip:=skip+1;
        if skip=70 then skip:=0;
       end;
  end;

 peak:=0.0;
 writeln(respfile,peak:8:1);

 close(respfile);

end; (* of procedure findit *)
```